Terrestrial Wildlife Responses to Climate Change

Steve Beissinger

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Biological Impacts of Climate Change

Parmesan, C. Annual Review of Ecology, Evolution, and Systematics 37: 637-669

1. Phenology - Advance of spring events (bud burst, flowering, breaking hibernation, migrating, breeding).

2. Mismatched Timing - Variation in phenological response has resulted in increasing asynchrony in predator-prey and insect-plant systems.

3. Poleward Range Shifts - have been documented for individual species, as have expansions of warm-adapted communities.

4. Disease Expansion - Shifts in abundances and ranges of parasites and their vectors are beginning to influence human disease dynamics.

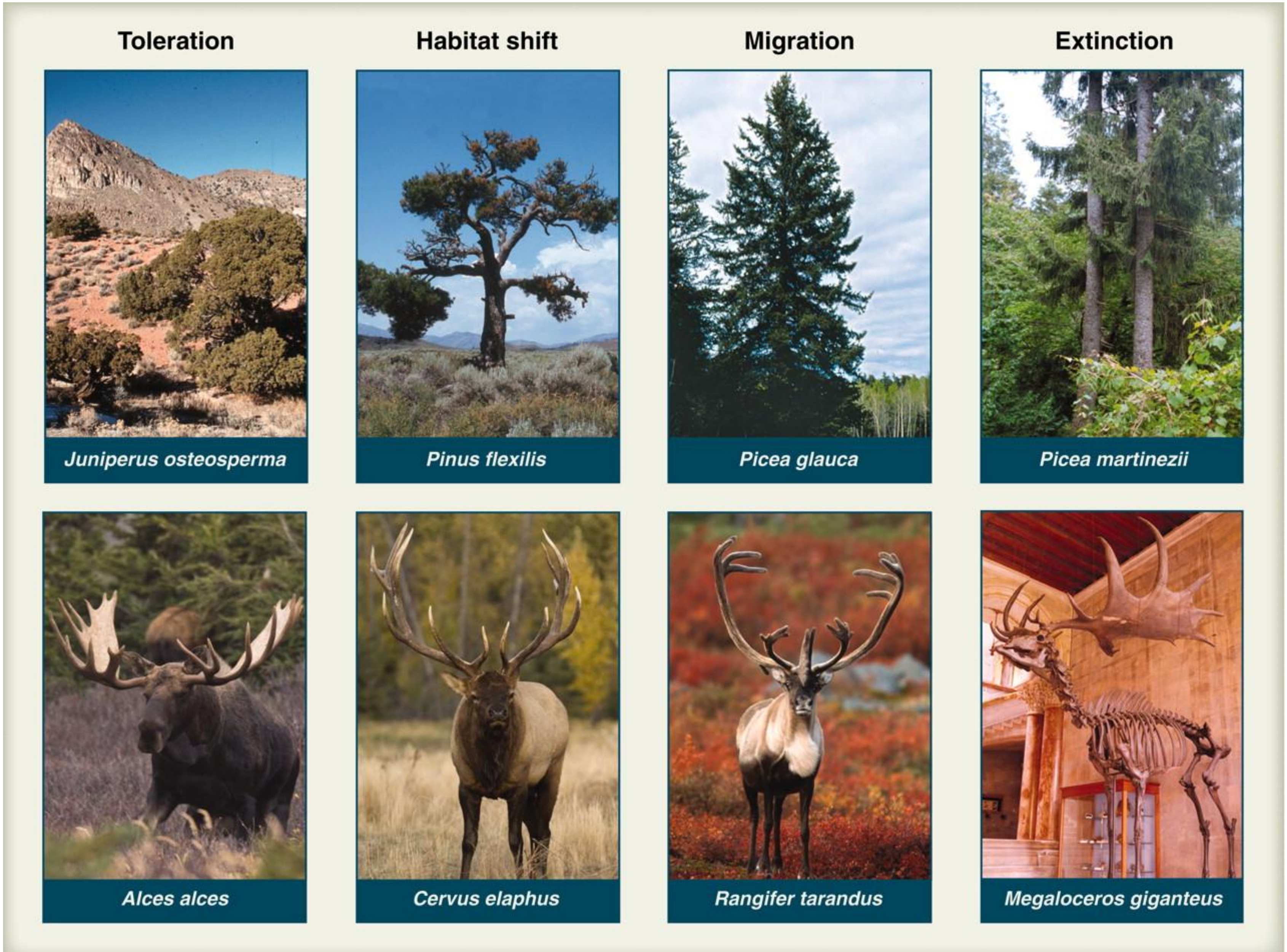
The Ultimate Biological Impact of Climate Change: Extinction

Parmesan, C. Annual Review of Ecology, Evolution, and Systematics 37: 637-669

5. Extinction - Range-restricted species, particularly polar and mountaintop species, show *more-severe range contractions* than other groups and *whole species have gone extinct* due to recent climate change.

PROBLEM – this conclusion is poorly supported. Need better historical data, which can come from collections, field notes, surveys, atlases, and species accounts.

Range Responses to Environmental Change



Dawson et al. Science 2011:332:53-58

Challenges in Comparing Historical and Contemporary Data

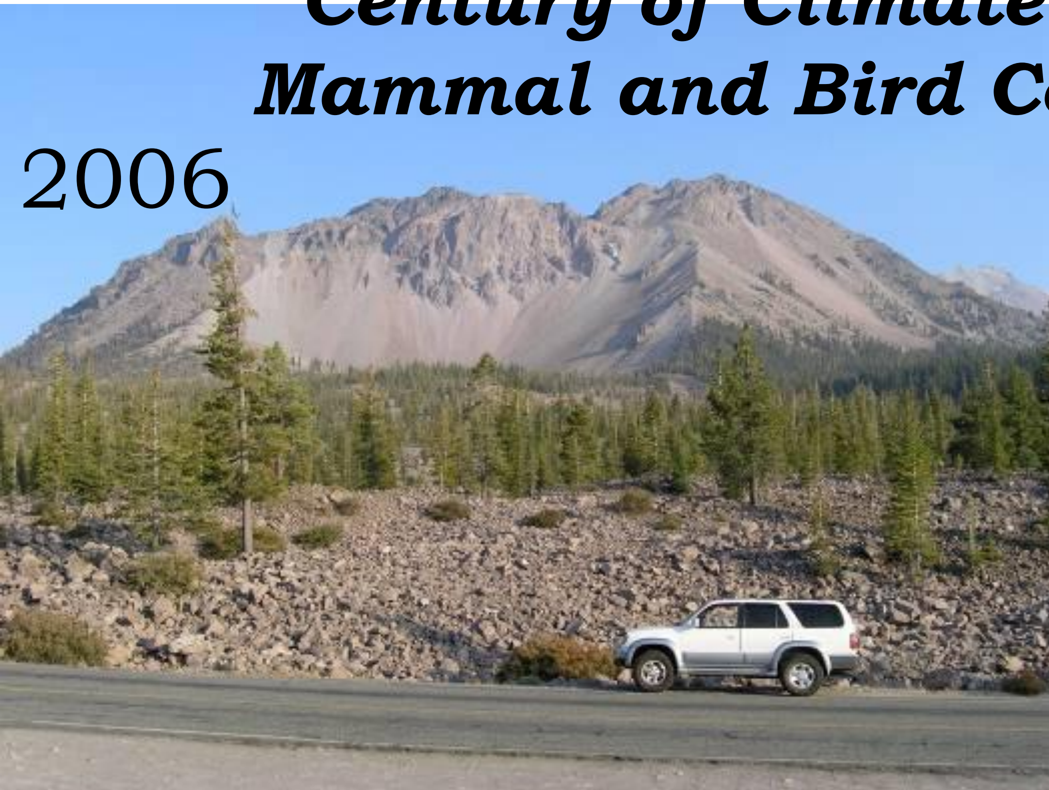
1. Data quality - non-standardized survey protocols and uncertain historical locations

2. *Survey data is often limited to detection and nondetection*

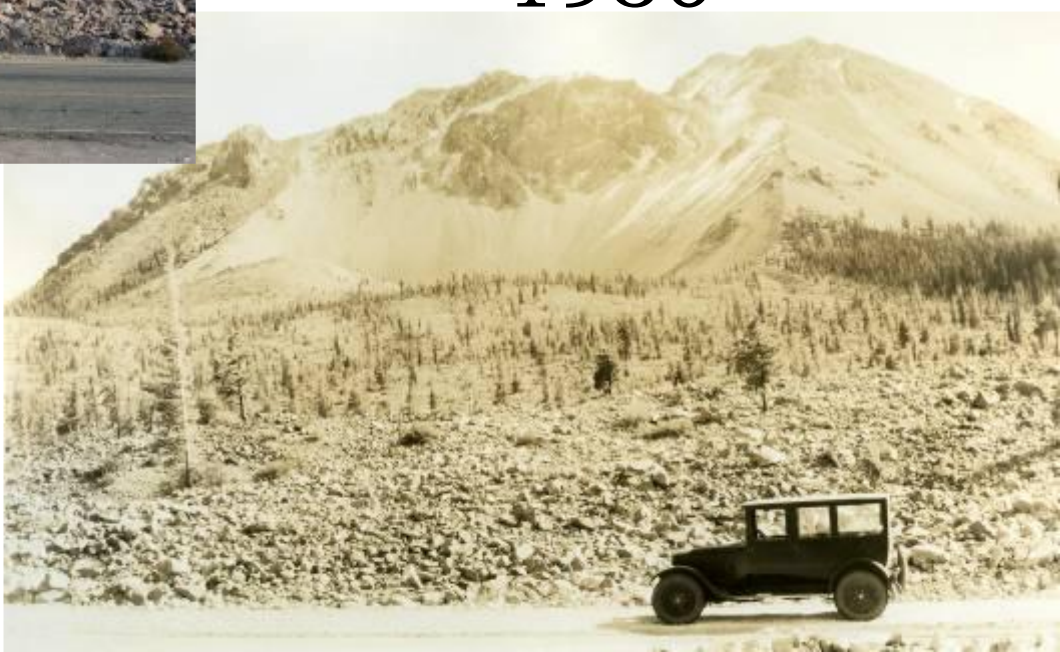
3. Ascribing causation to changes that are observed – historical vegetation and climate data are often lacking.

The Grinnell Resurvey Project: Impact of a Century of Climate Change on Small Mammal and Bird Communities in California

2006



1930



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Grinnell Resurvey Team

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Morgan Tingley

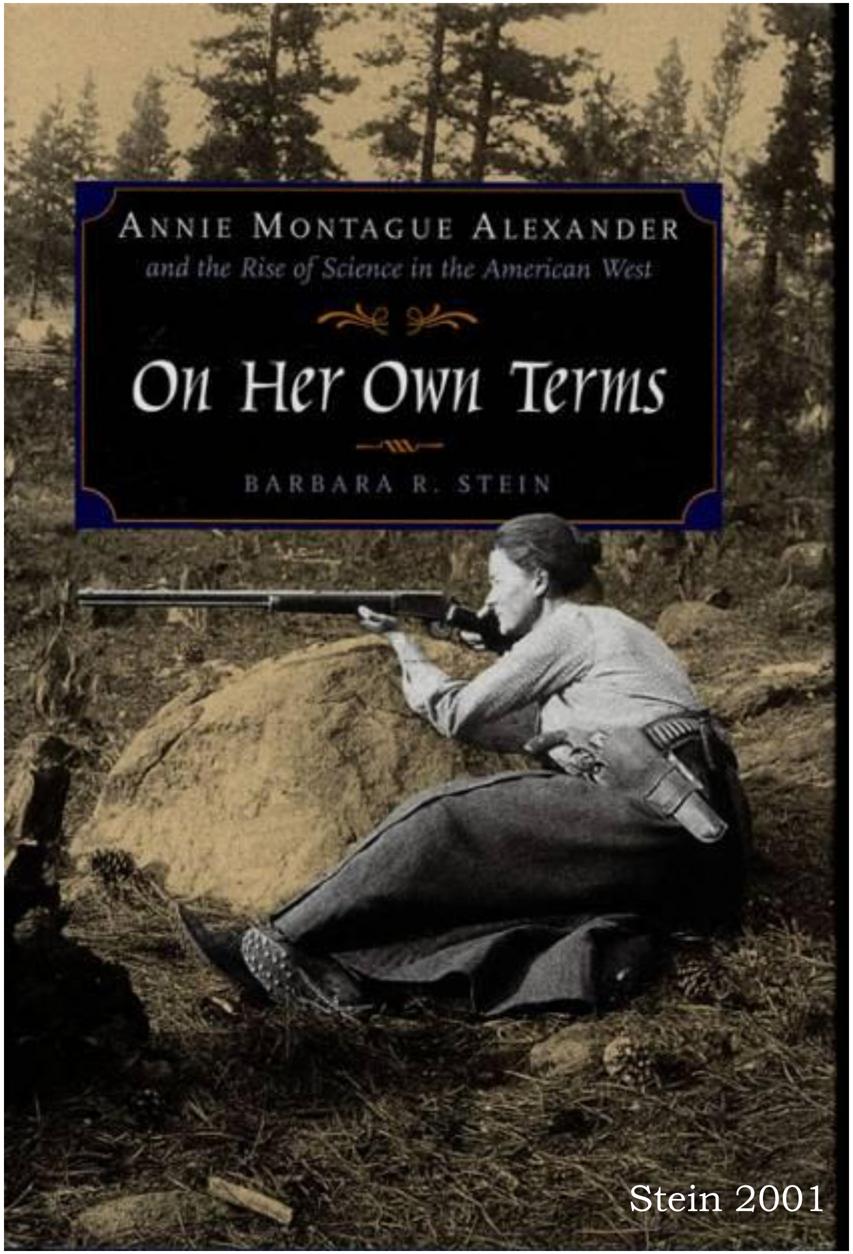
Michelle Koo

Adam Smith

Pete Epanchin

Annie Alexander

Museum of Vertebrate Zoology was Founded in 1908

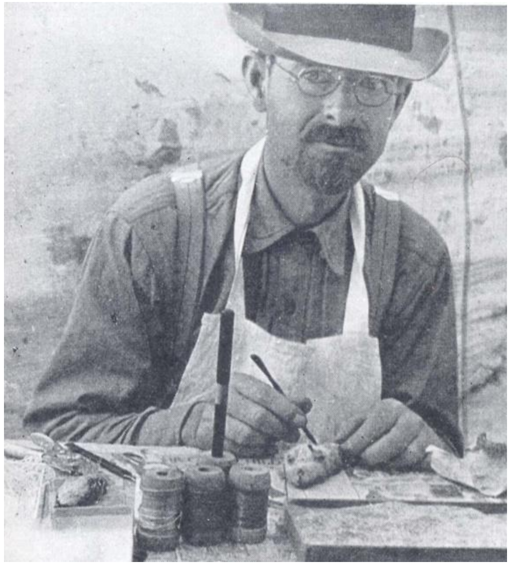


Stein 2001

Joseph Grinnell

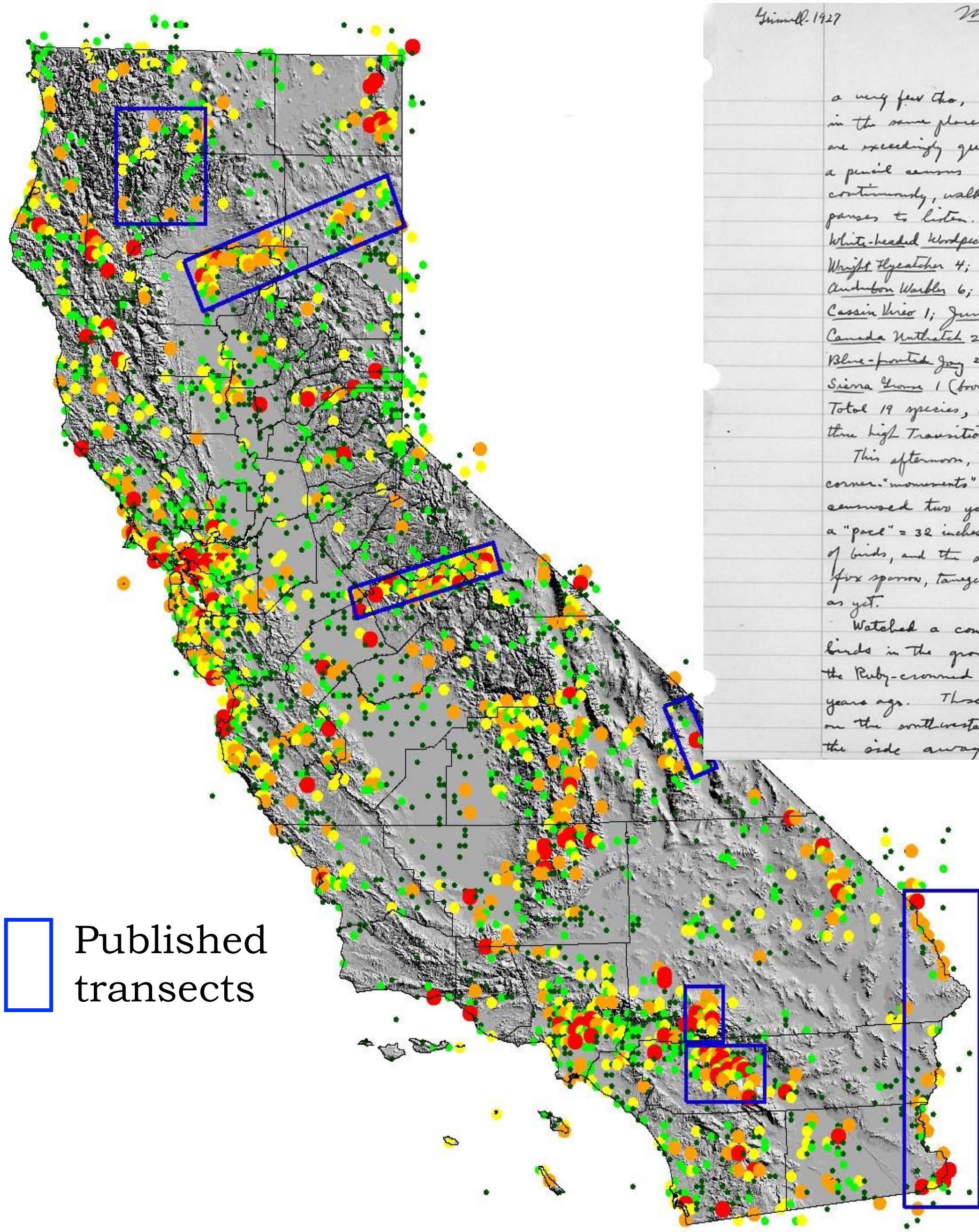
The Grinnell Legacy

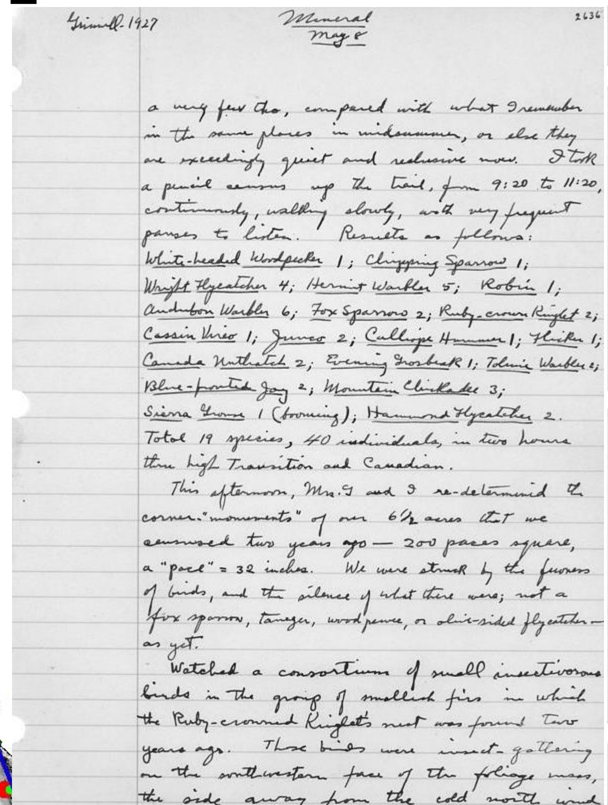
"At this point I wish to emphasize what I believe will ultimately prove to be the greatest purpose of our museum. This value will not, however, be realized until the lapse of many years, ***possibly a century***, assuming that our material is safely preserved. *And this is that the student of the future will have access to the original record of faunal conditions in California and the west, where ever we now work*" (Grinnell, 1910)



Joe Grinnell, MVZ
Director 1908-39

Pre-1940 MVZ Specimen Locality Records




Grinnell 1927

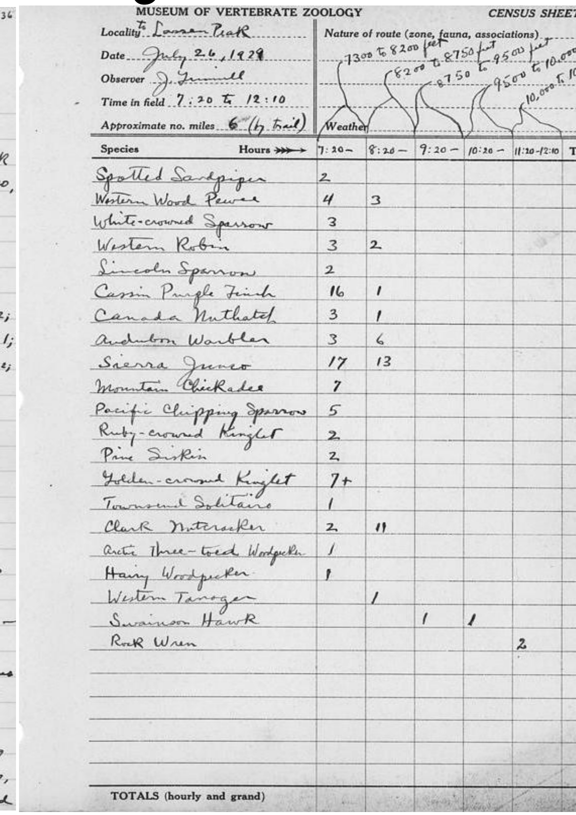
Mineral
May 8

2636

a very few tho, compared with what I remember in the same places in midsummer, or else they are exceedingly quiet and reclusive now. I took a pencil census up the trail, from 9:20 to 11:20, continuously, walking slowly, with very frequent pauses to listen. Results as follows: White-headed Woodpecker 1; Chipping Sparrow 1; Wright Flycatcher 4; Hermit Warbler 5; Robin 1; Audubon Warbler 6; Fox Sparrow 2; Ruby-crown Kinglet 2; Cassin Vireo 1; Junco 2; Calliope Humm 1; Flicker 1; Canada Nuthatch 2; Evening Grosbeak 1; Tolmie Warbler 2; Blue-fronted Jay 2; Mountain Chickadee 3; Sierra Grouse 1 (booming); Hammond Flycatcher 2. Total 19 species, 40 individuals, in two hours thru high Transition and Canadian.

This afternoon, Mrs. G and I re-determined the corner "monuments" of our 6½ acres that we censused two years ago — 200 paces square, a "pace" = 32 inches. We were struck by the fewness of birds, and the silence of what there were; not a fox sparrow, tanager, wood pewee, or olive-sided flycatcher — as yet.

Watched a consortium of small insectivorous birds in the group of smallish firs in which the Ruby-crowned Kinglet's nest was found two years ago. These birds were insect-gathering on the southwestern face of the foliage mass, the side away from the cold north wind


MUSEUM OF VERTEBRATE ZOOLOGY — CENSUS SHEET

Locality to Lassen Peak
Date July 26, 1928
Observer J. Grinnell
Time in field 7:20 to 12:10
Approximate no. miles 6 (by trail)
Nature of route (zone, fauna, associations): 7300 to 8200 feet; 8200 to 8750 feet; 8750 to 9500 feet; 9500 to 10,000 feet; 10,000 to 10...
Weather

Species / Hours	7:20–	8:20–	9:20–	10:20–	11:20–12:10
Spotted Sandpiper	2				
Western Wood Pewee	4	3			
White-crowned Sparrow	3				
Western Robin	3	2			
Lincoln Sparrow	2				
Cassin Purple Finch	16	1			
Canada Nuthatch	3	1			
Audubon Warbler	3	6			
Sierra Junco	17	13			
Mountain Chickadee	7				
Pacific Chipping Sparrow	5				
Ruby-crowned Kinglet	2				
Pine Siskin	2				
Golden-crowned Kinglet	7+				
Townsend Solitaire	1				
Clark Nutcracker	2	11			
Arctic Three-toed Woodpecker	1				
Hairy Woodpecker	1				
Western Tanager		1			
Swainson Hawk			1	1	
Rock Wren					2
TOTALS (hourly and grand)					

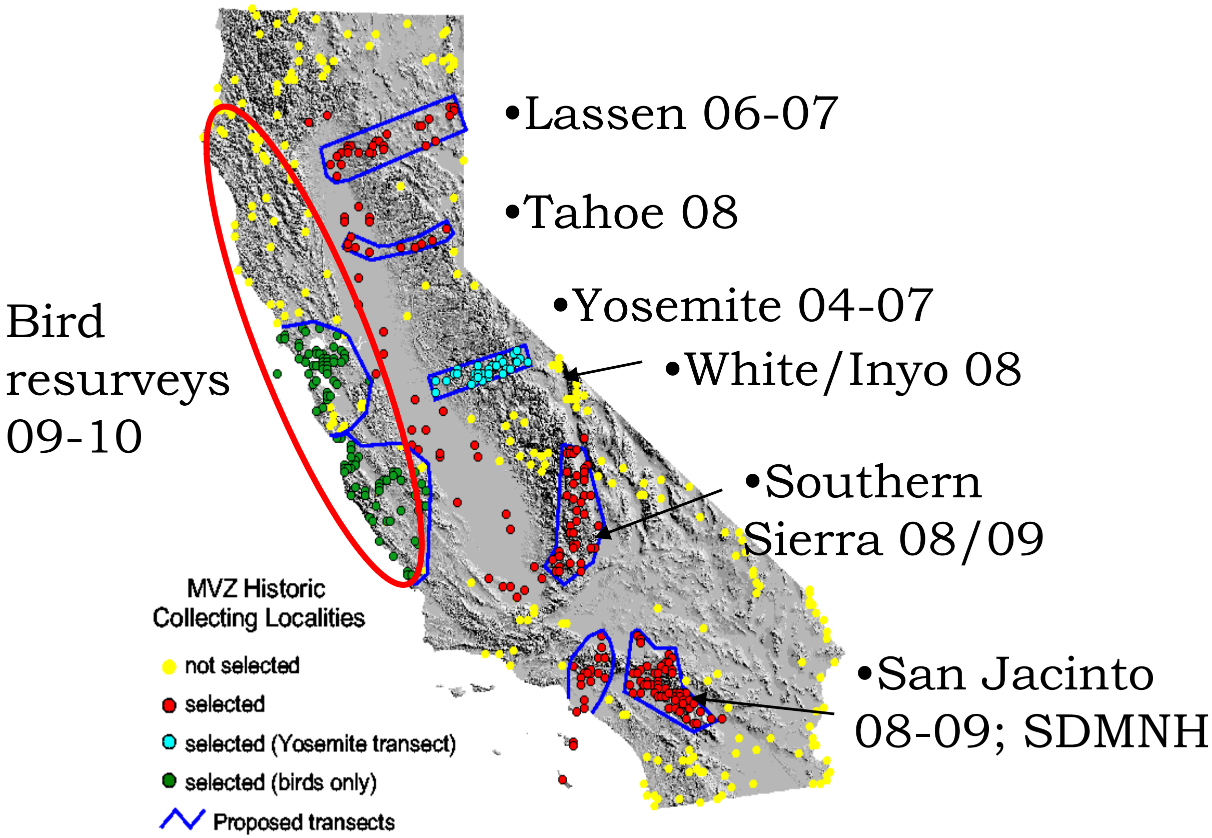
Field Notes

~ 3 times more species per site **observed** than **collected**

Narrative of Ward Russell, the MVZ's preparator for 40 years, doing field work with Grinnell

(*From an interview with Ward at his home in Berkeley, 4 March 1992, by Oliver P. Pearson, Professor Emeritus and former MVZ Director*)

Grinnell Project: Status and Future

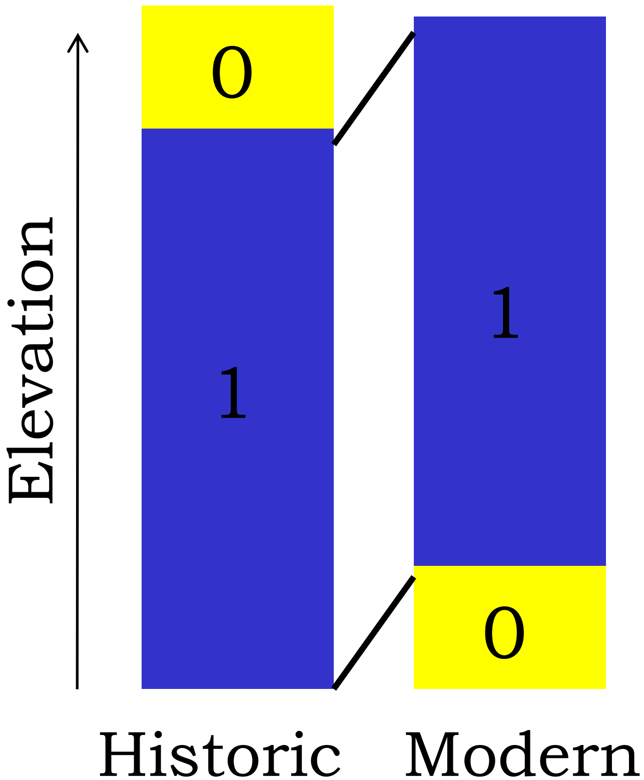


- Continuing resurveys
- Modeling past change (08-11)
- Predicting future change (09-12)

Issues in Detecting Range Change Using Historical Data

The challenge is making unbiased comparisons between historic and contemporary data:

- Survey observers, methods, and effort differ over time
- Uncertainty about a "true" absence

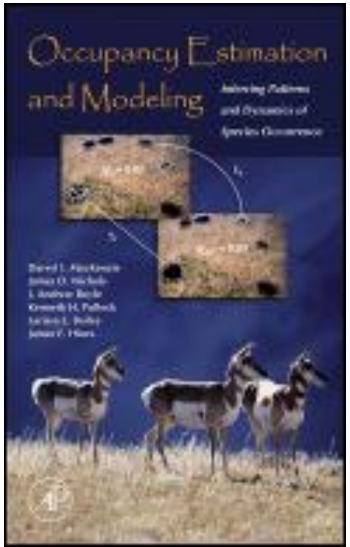


Tingley and Beissinger. 2009. TREE 24:625-633.

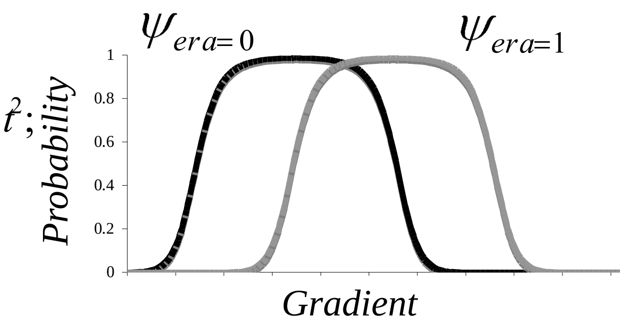
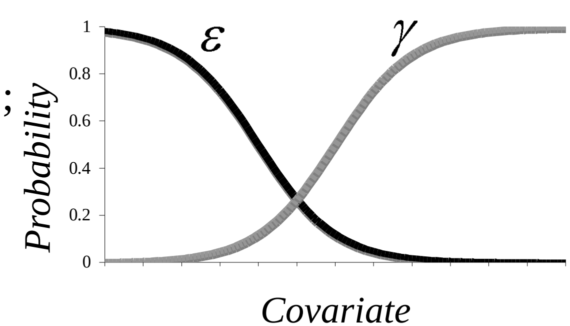
Occupancy Models

- Investigate patterns in occupancy using **presence-absence data**.
- Recognize that an observed ‘absence’ may be the result of a **true absence or a nondetection**.
- Depend on **repeated surveys over a short (closed) time period** to determine presence or absence of a target species.

MacKenzie et al. (Ecology 2002, 2004; book in 2006) provide a general treatment of the topic.



Parameterizations of Occupancy Models For Inferring Range Shifts

Model	Sites	Modeled Parameters	Example Equations	Range Change Inference
Single Season	Unpaired	ψ, p	$\text{logit}(\psi) = \beta_0 + \beta_1 \cdot era + \beta_2 \cdot gradient + \beta_3 \cdot gradient^2;$ $\text{logit}(p) = \beta_4$	
Multi-Season	Paired	$\psi_0, \varepsilon, \gamma, p$	$\text{logit}(\psi_0) = \beta_0 + \beta_1 \cdot \text{covariate} + \beta_2 \cdot gradient^2;$ $\text{logit}(\varepsilon) = \beta_3 + \beta_4 \cdot \text{covariate};$ $\text{logit}(\gamma) = \beta_5 + \beta_6 \cdot \text{covariate};$ $\text{logit}(p) = \beta_7$	

Single Season Occupancy Models

For a series of species' presences (1) and absences (0) observed in repeated surveys at each site: h_1, h_2,...h_s (1,0,1,0,0,0)

$$L(\psi, \mathbf{p} \mid h_1, h_2, ..h_s) = \left[\psi^{n.} \prod_{t=1}^{T} p_t^{n_t} (1 - p_t)^{n. - n_t}\right] \times \left[\psi \prod_{t=1}^{T} (1 - p_t) + (1 - \psi)\right]^{N - n.}$$

where:

ψ - the probability a species is present (occupancy)

p - the probability of detection

N - the total number of sites surveyed

T - the number of distinct sampling occasions

$n.$ - the total number of sites at which the species was detected at least once

n_t - the number of sites where the species was detected at time t.

Inference from Occupancy Models About False Absence Across a Set of Sites

The probability of detection at a site (P*), based on the number of samples at a site (k) and any covariates (e.g., trapping effort, observer), is:

$$\mathbf{P^*} = 1-\prod_{i=1}^{k}(1-p_i)$$

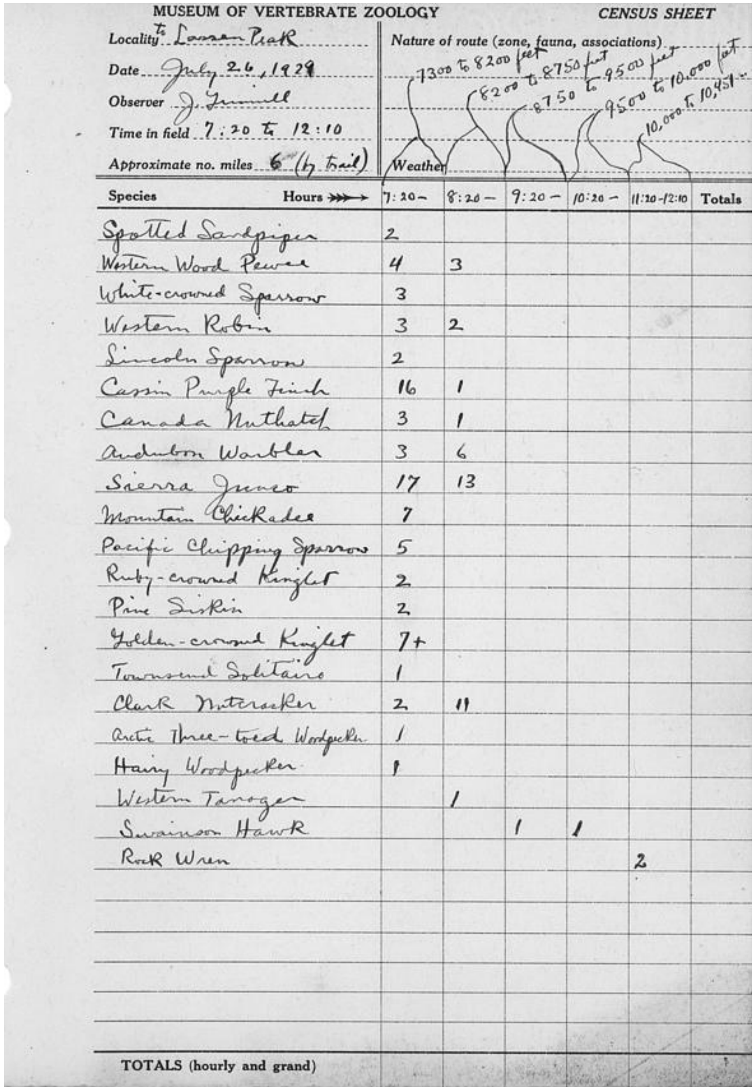
The probability of a false absence from a site ($P_{fa(site)}$) is:

$$\mathbf{P_{fa(site)} = 1 - P^*_{(site)}}$$

The probability of a false absence across a set of *n* sites (P_{fa}) is:

$$\mathbf{P_{fa}} = \prod_{i=1}^{n} P_{fa(site)}$$

Challenge with Historic Bird Data: Survey Methods Change Over Time



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Weather

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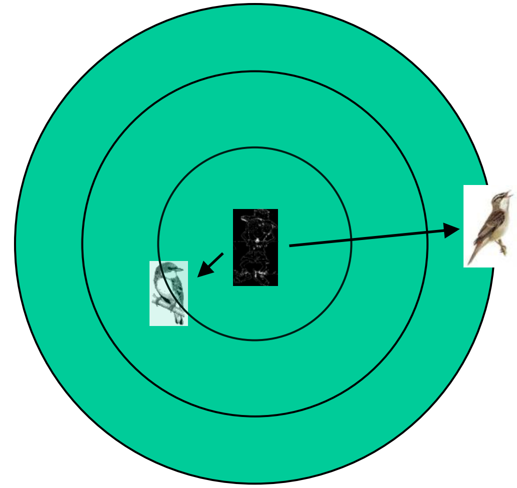
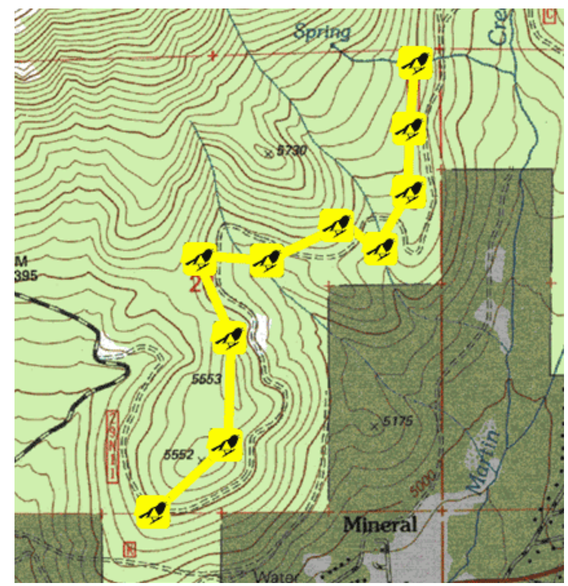
Ruby-crowned Kinglet	2					
Pine Siskin	2					
Golden-crowned Kinglet	7+					
Townsend Solitaire	1					
Clark Nutcracker	2	11				
Arctic Three-toed Woodpecker	1					
Hairy Woodpecker	1					
Western Tanager		1				
Swainson Hawk			1	1		
Rock Wren					2	
TOTALS (hourly and grand)						

Timed surveys along elevational path





7 min unlimited-radius point counts along same path

Detectability Results for 43 Bird Species

Candidate Detection Models

(.)

Era

Julian day

Observer

Era + Julian Day

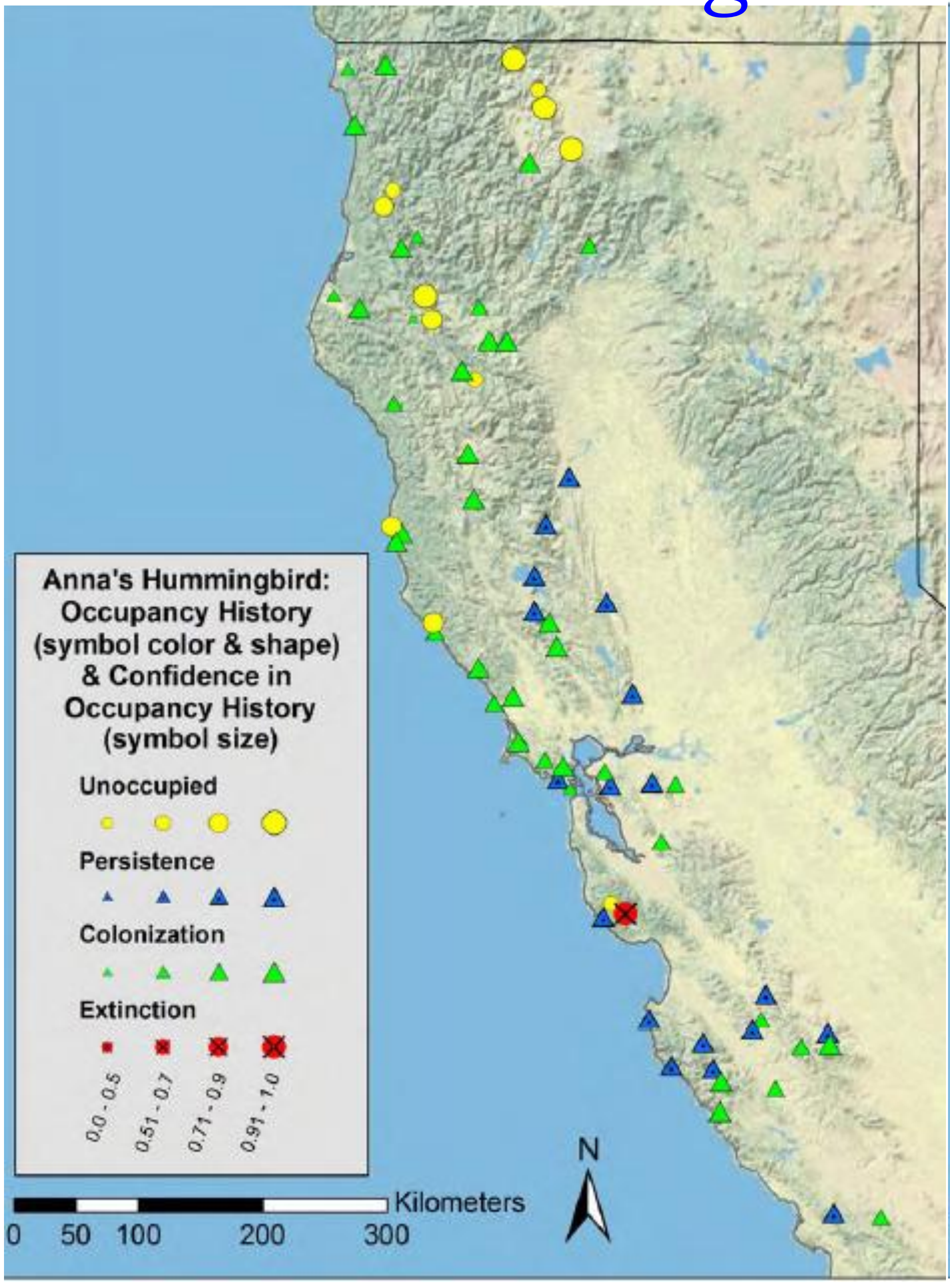
Era * Julian Day

Observer + Julian Day

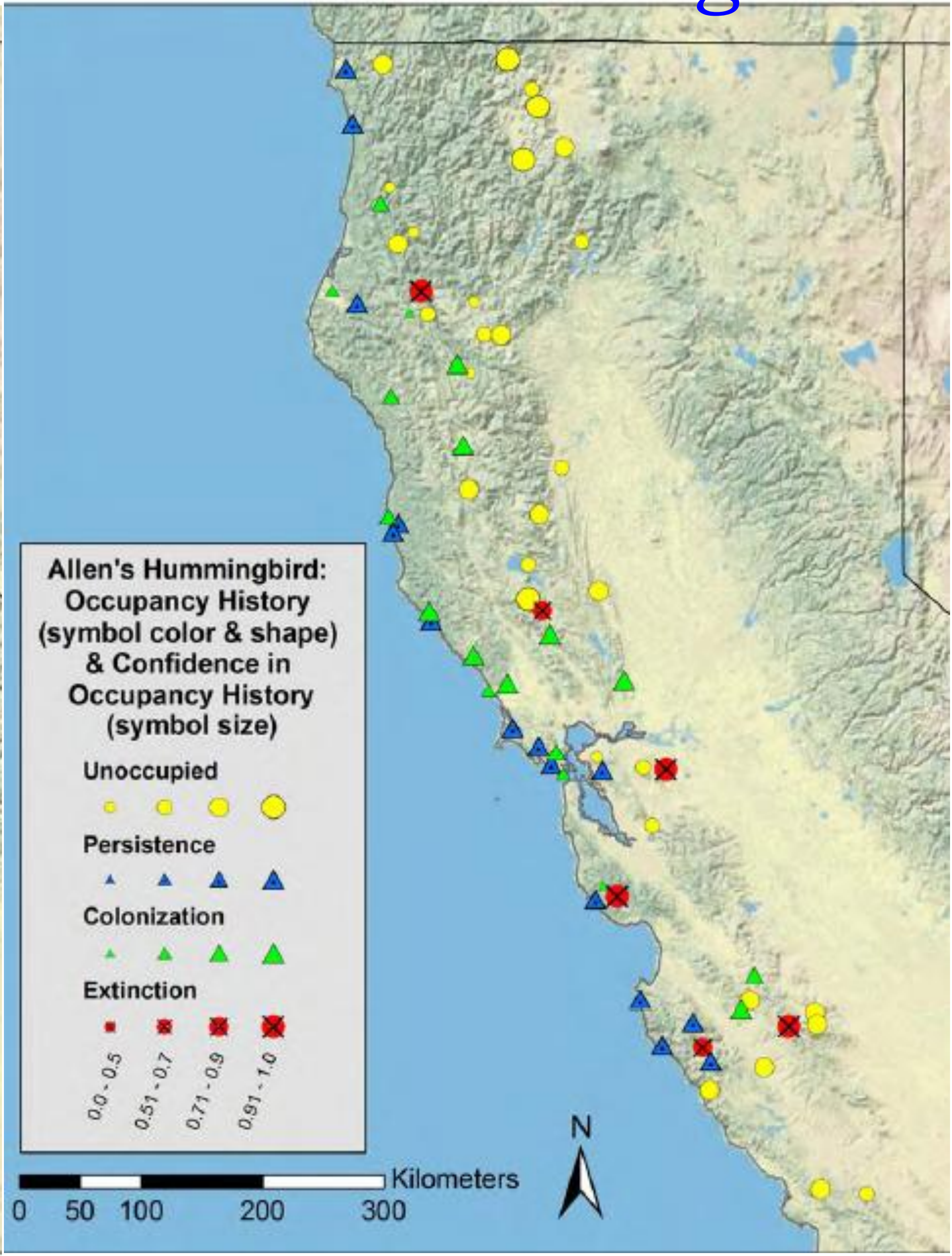
Observer + Julian Day + Julian Day * Era

Parameter	Average Cumulative AIC Weight
Observer	0.34
Era	0.89
Julian Day	0.71

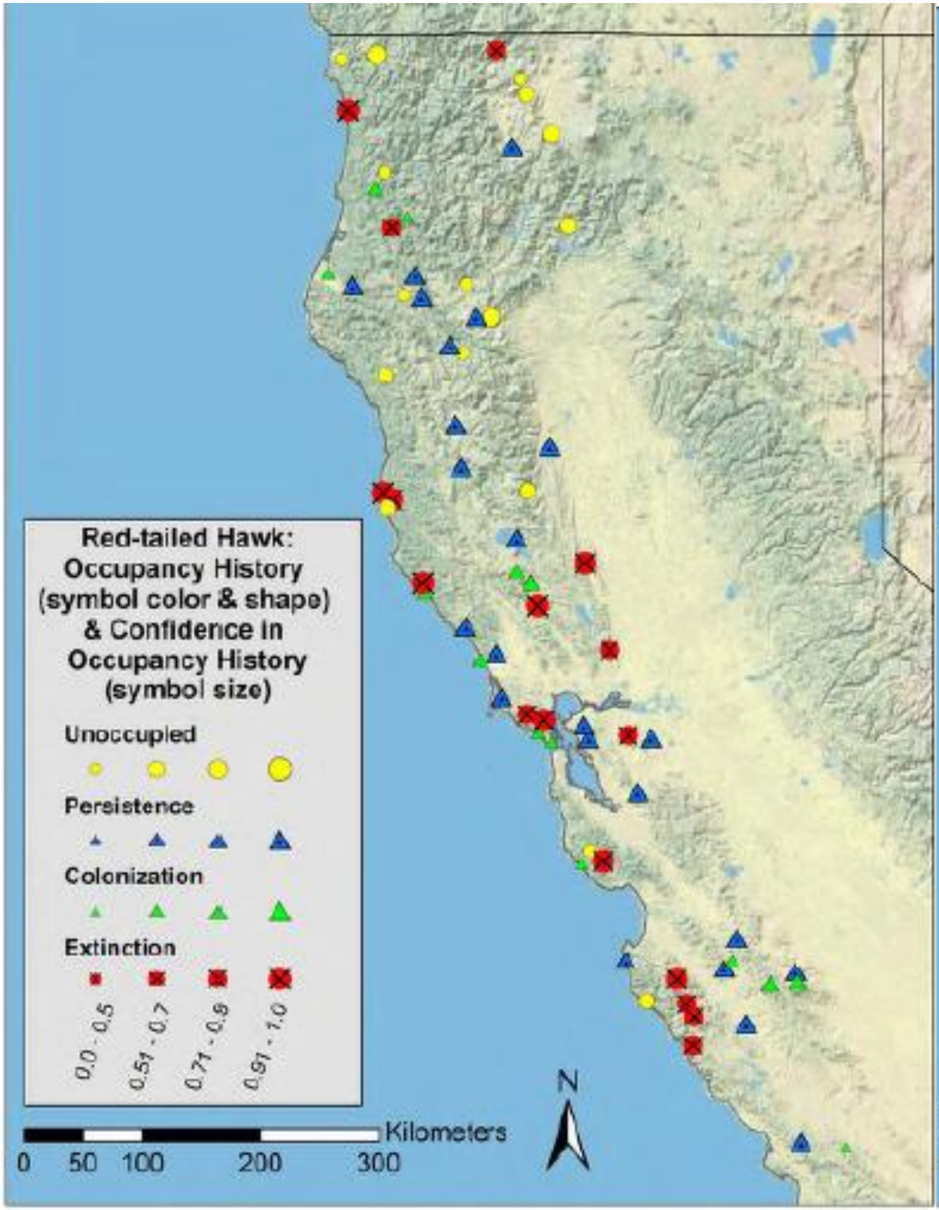
Anna's Hummingbird



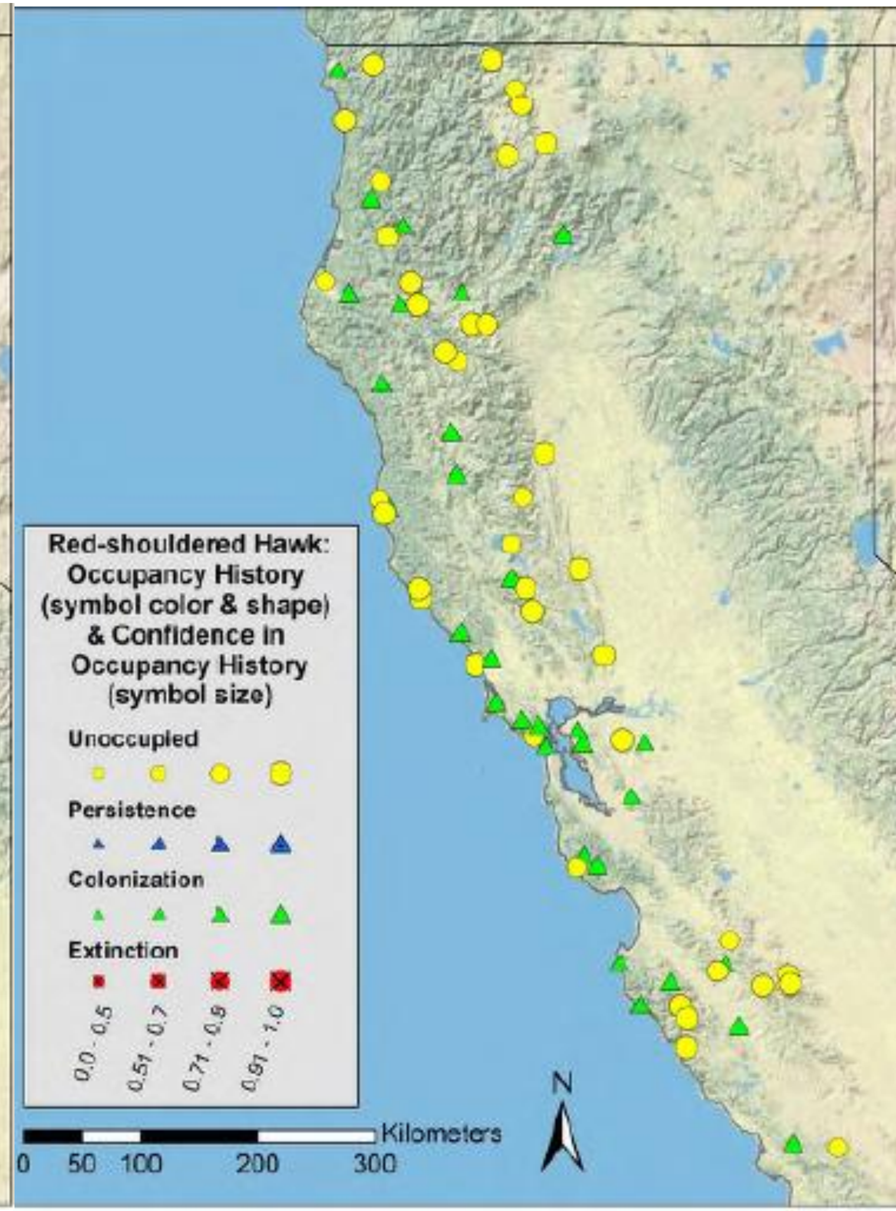
Allen's Hummingbird



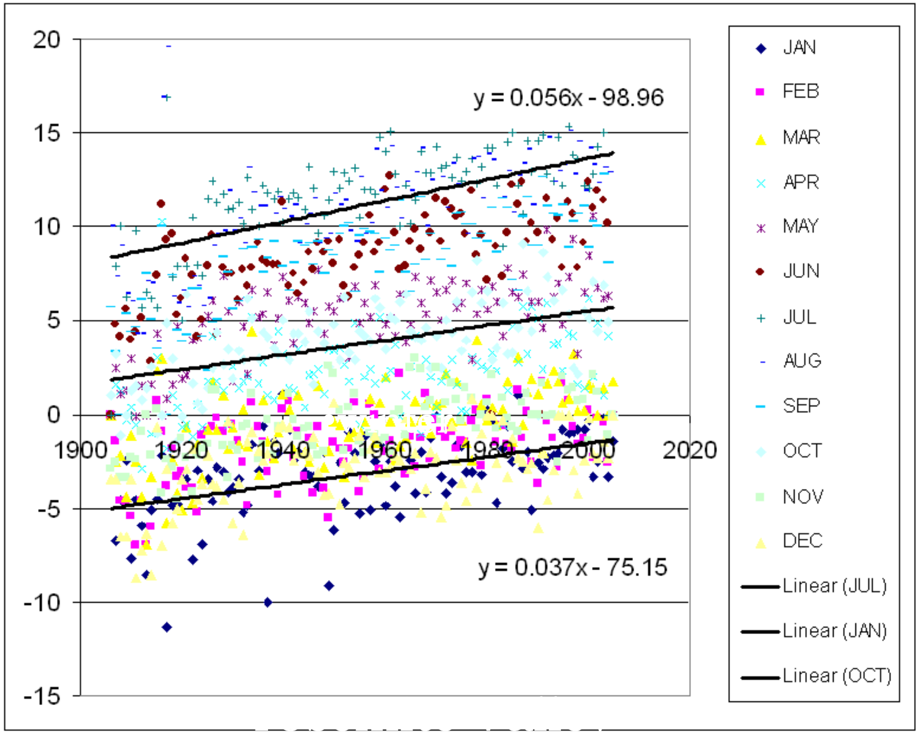
Red-tailed Hawk



Red-shouldered Hawk



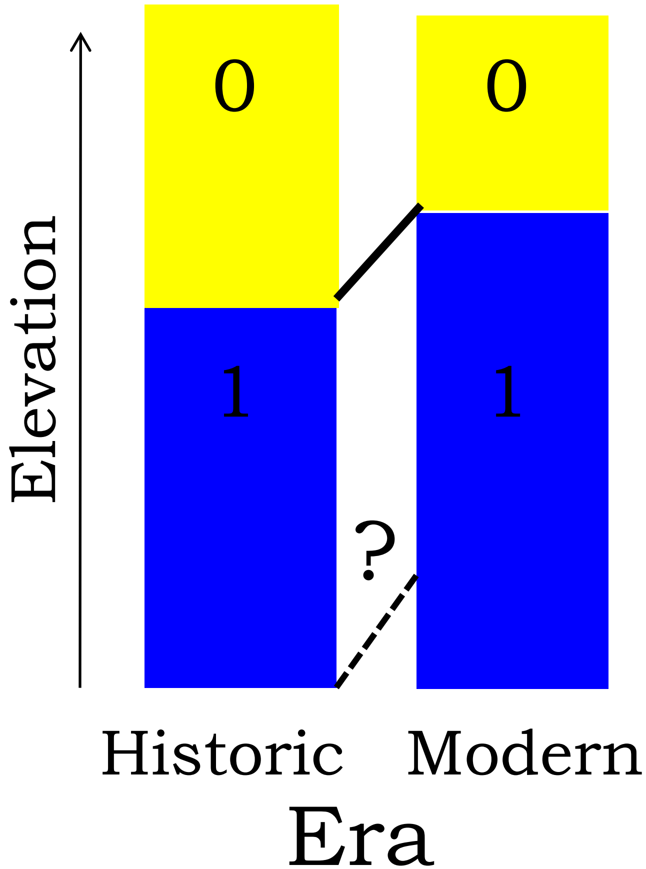
Signatures of Climate Change in Yosemite: Temperature Increase and Glacial Melt



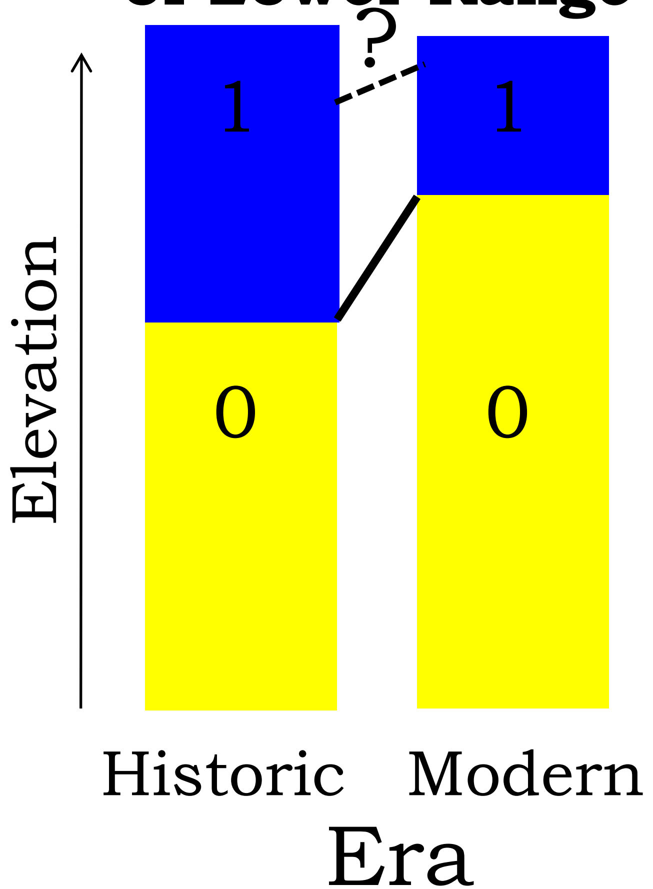
Minimum temperatures of the central Sierras have warmed by 3-4 C over the past 100 years.

Range Change Predictions with Climate Warming

Low-Mid Elevation Species: Expansion of Upper Range



Mid-High Elevation Species: Contraction of Lower Range



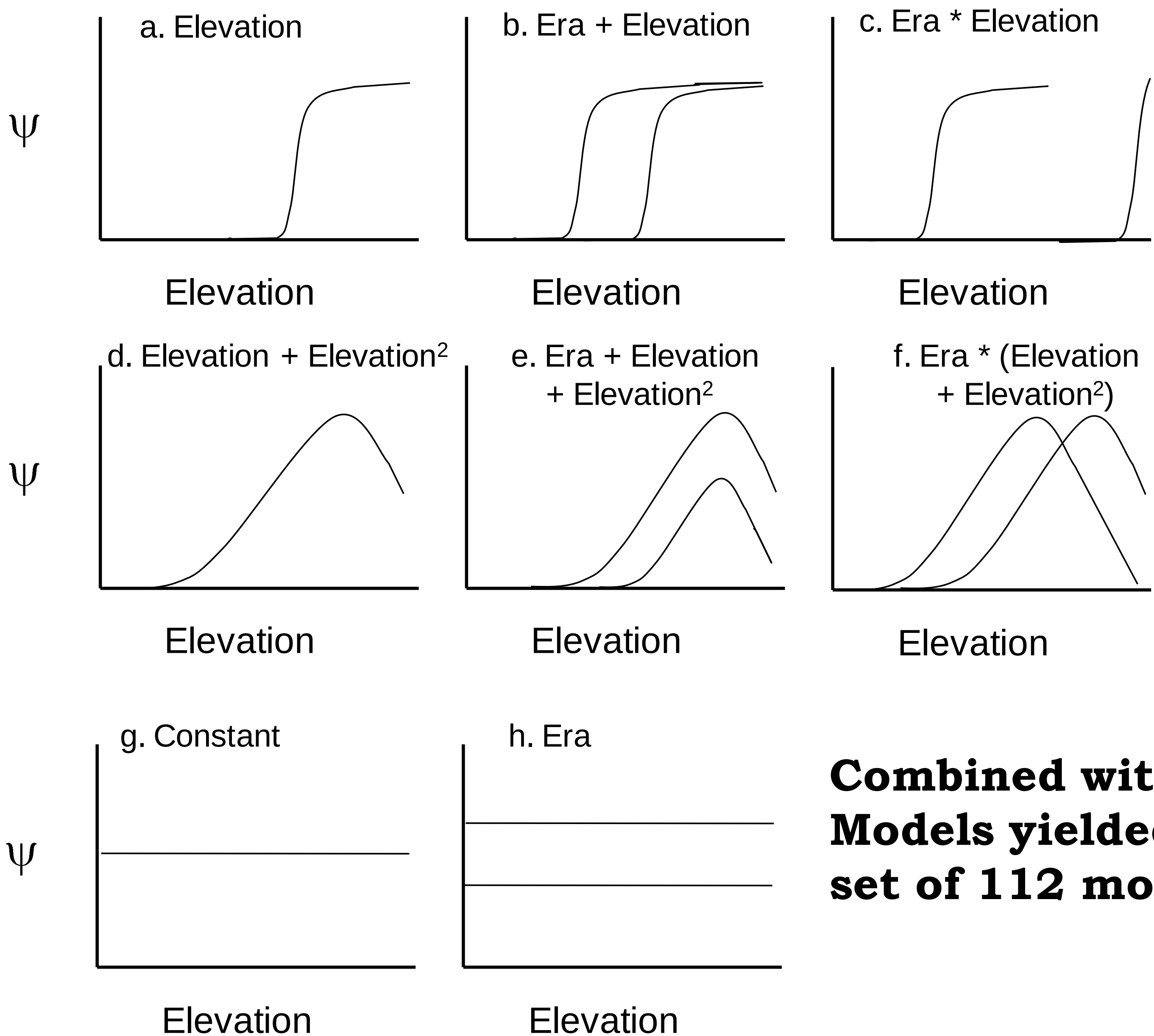
We fit 36 candidate detection models using:

For Mammals:

- **Era** (Grinnell vs. Modern)
- **Trend** (declining success by night)
- **Trapping effort** (mean and log number of traps per night)
- And **combinations** and **interactions** (multiplicative and additive).

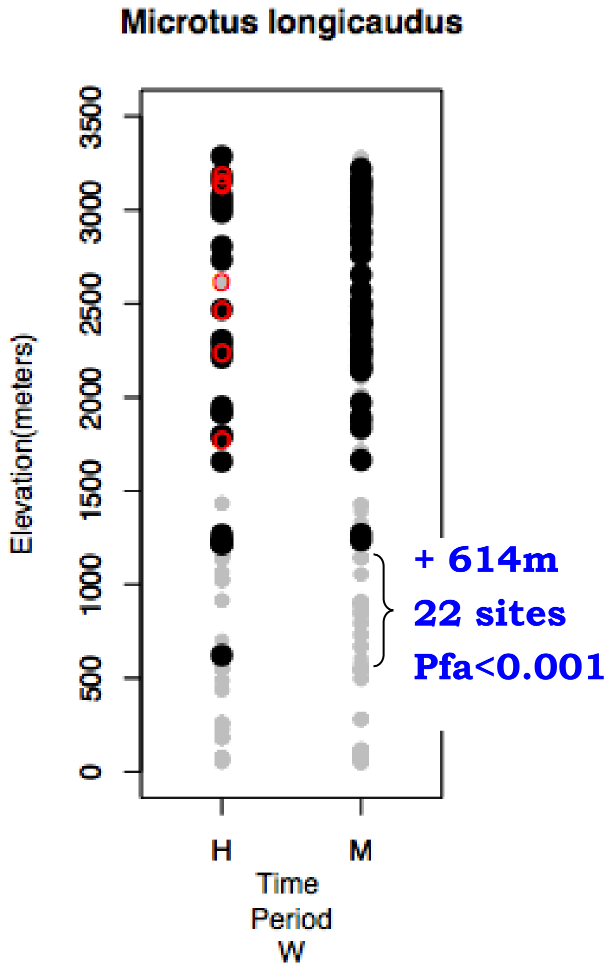
The 14 best detection models were used with 8 potential occupancy models with elevation.

8 Potential Occupancy (Ψ) Models

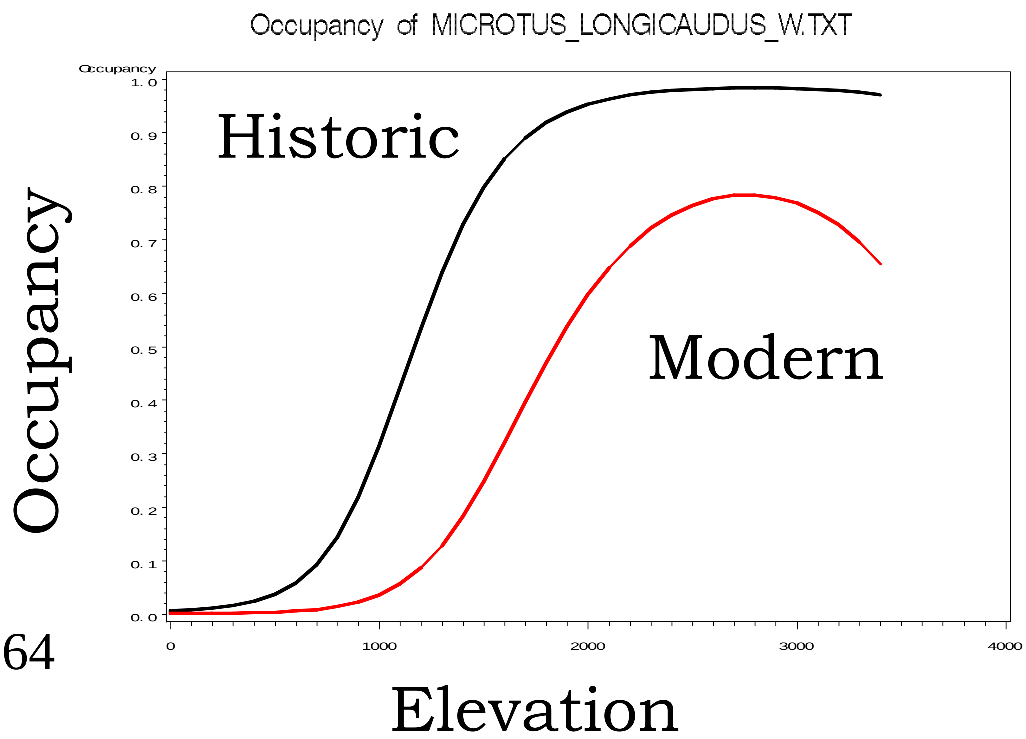


Combined with 14 detection Models yielded a candidate set of 112 models.

Microtus longicaudus



Occupancy models	Cumulative AIC Wt
Constant	0.00
Elev	0.00
Elev+Elev^2	0.00
Era	0.00
Era*(Elev + Elev^2)	0.19
Era*Elev	0.03
Era+Elev	0.04
Era+Elev+Elev^2	0.74



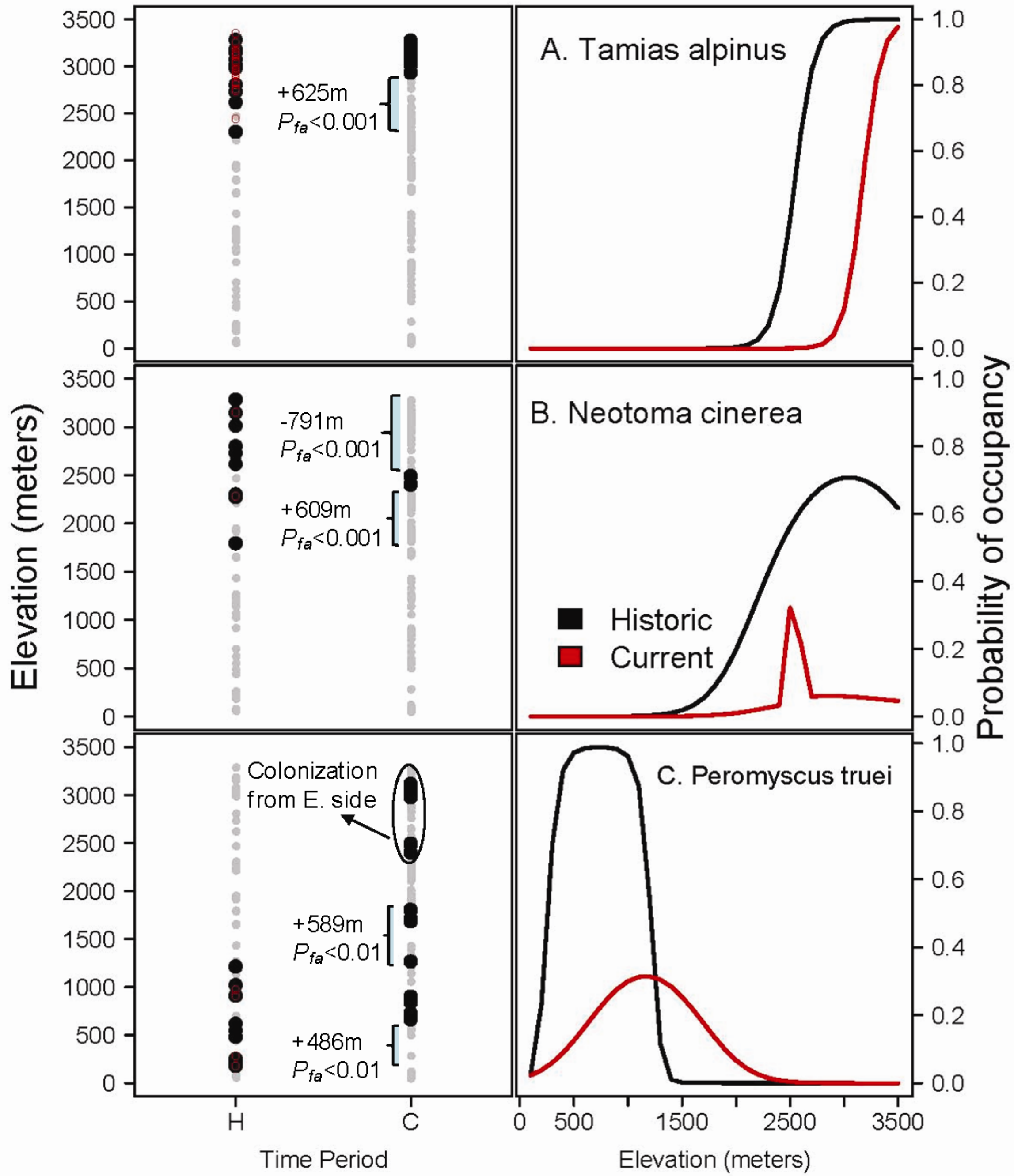
Moritz et al. 2008. Science 322:261-264

Trapping Data and Occupancy Profiles

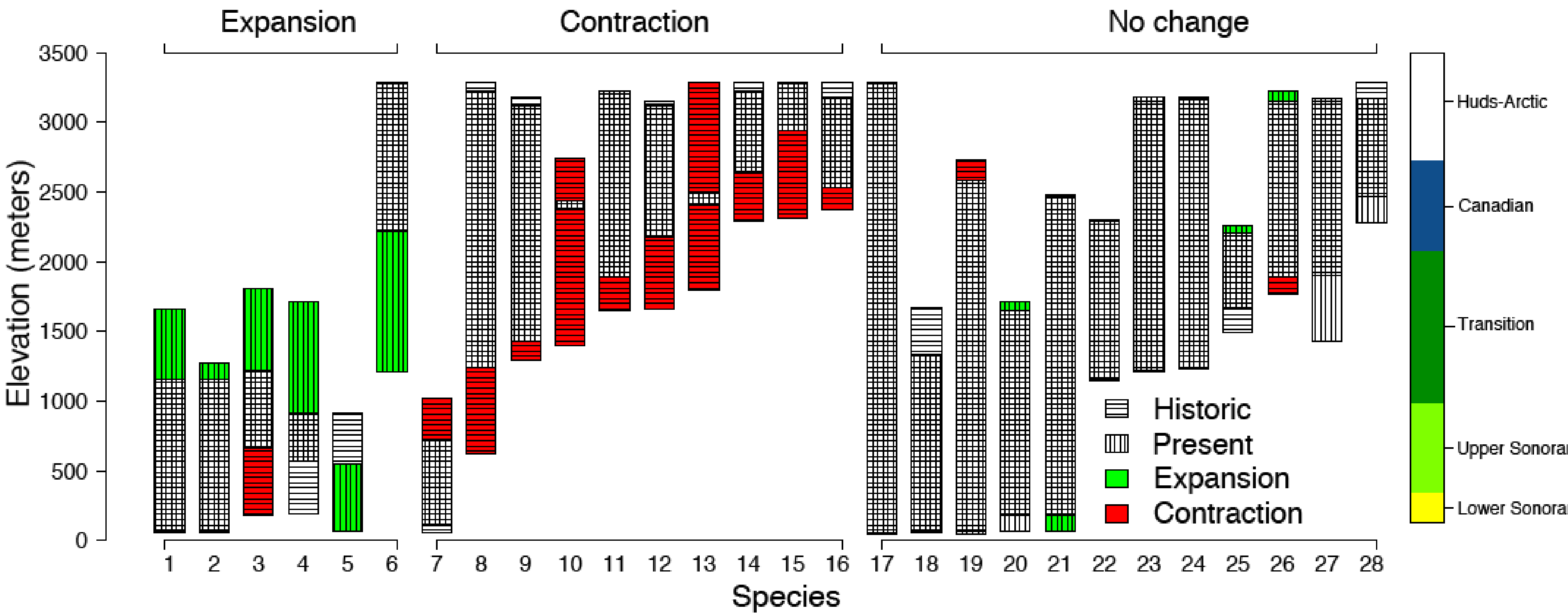
Alpine chipmunk
Tamias alpinus

Wood rat
Neotoma cinerea

Piñon mouse
Peromyscus truei



Elevational Range Change for 28 Yosemite Small Mammal Species



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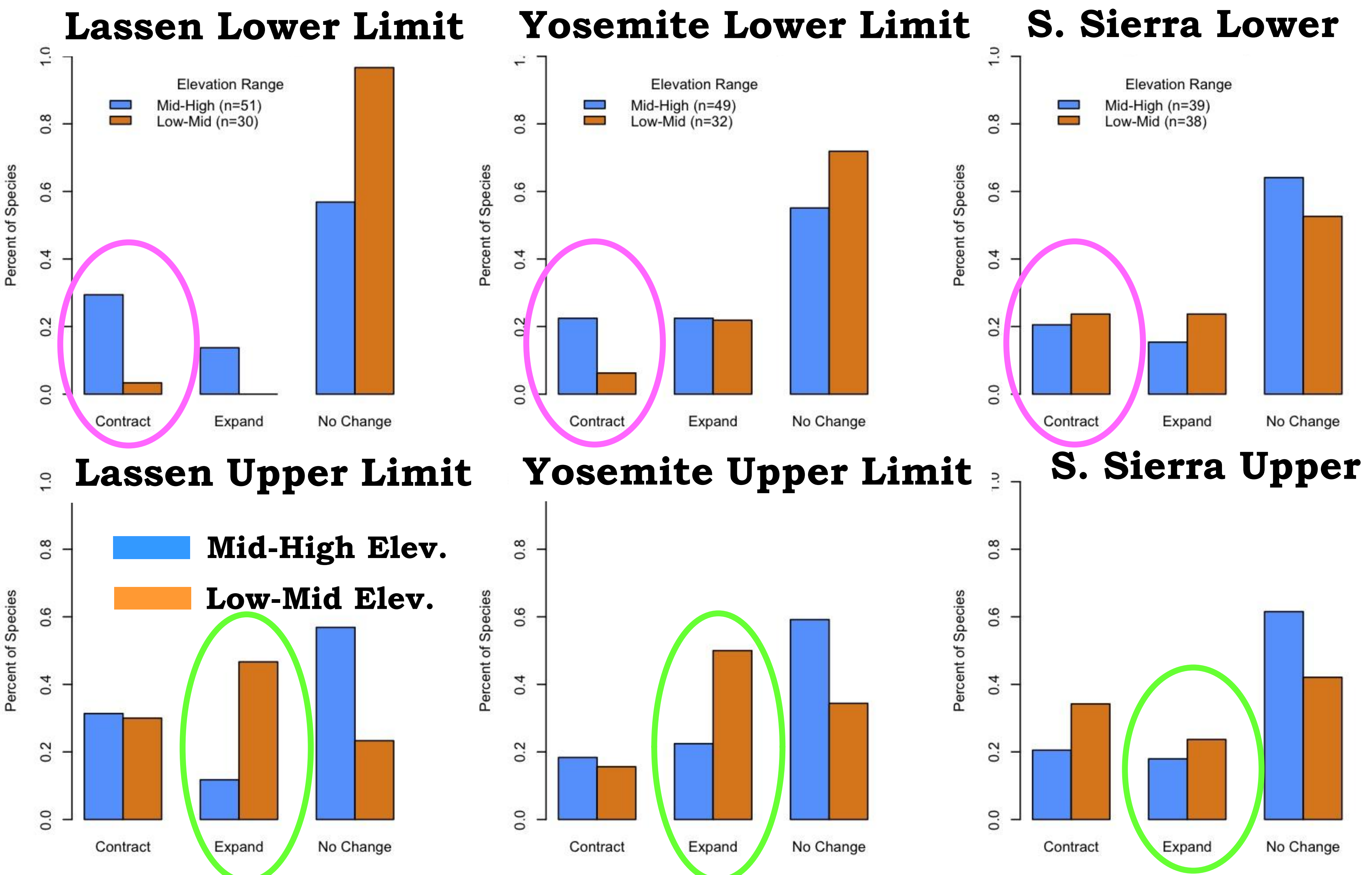
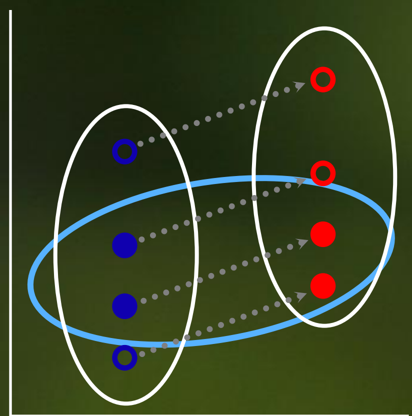
Range Changes in Sierra Birds

Elevation Range: Mid-High Low-Mid Elev.

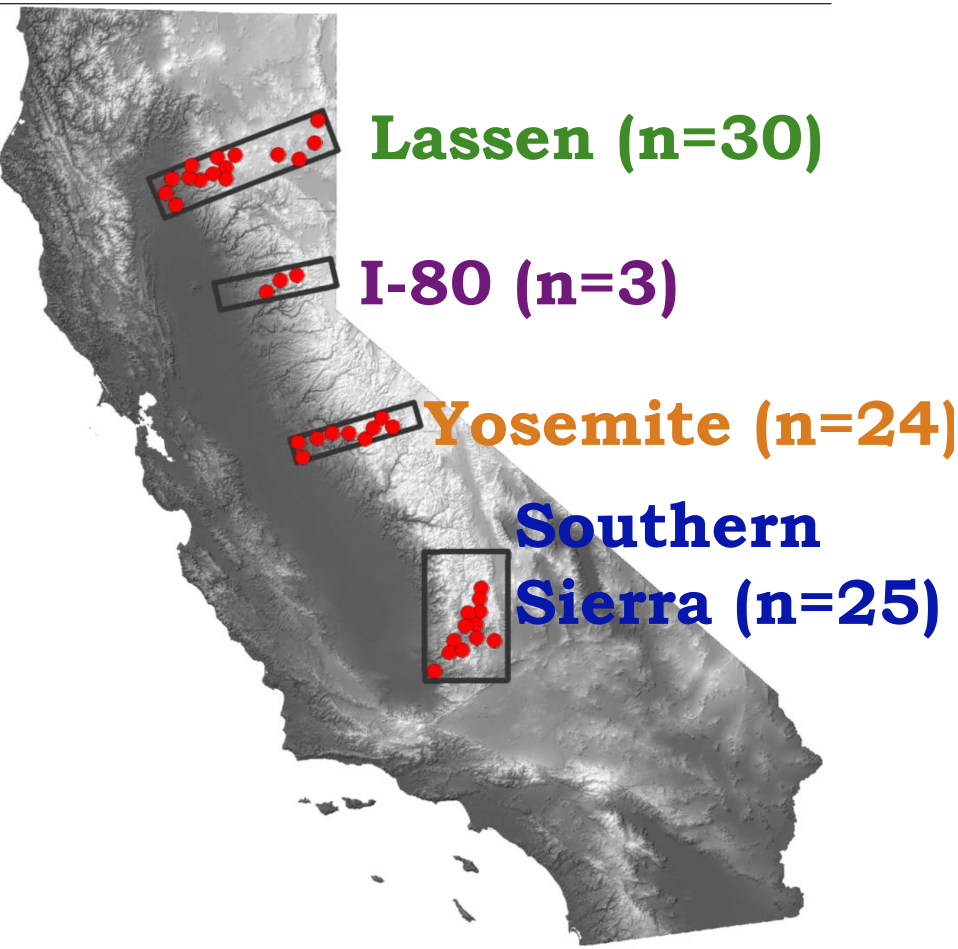


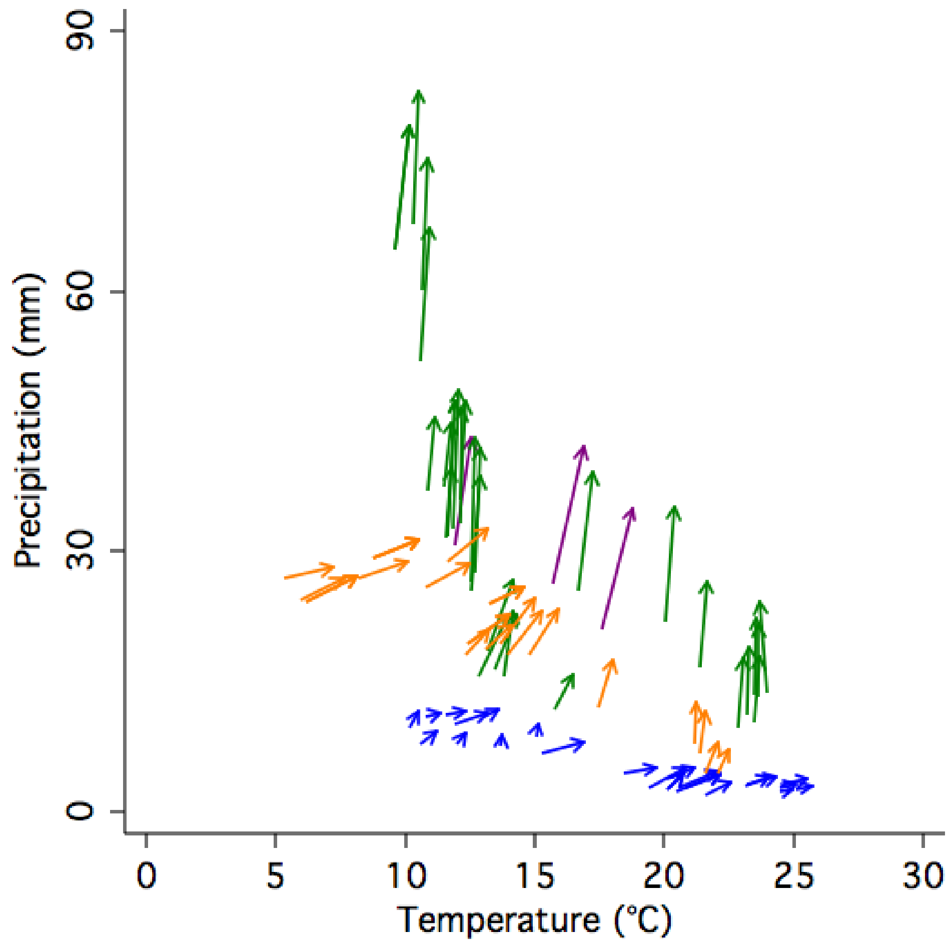
Causation: Do birds track their climatic niche in response to a century of climate change?



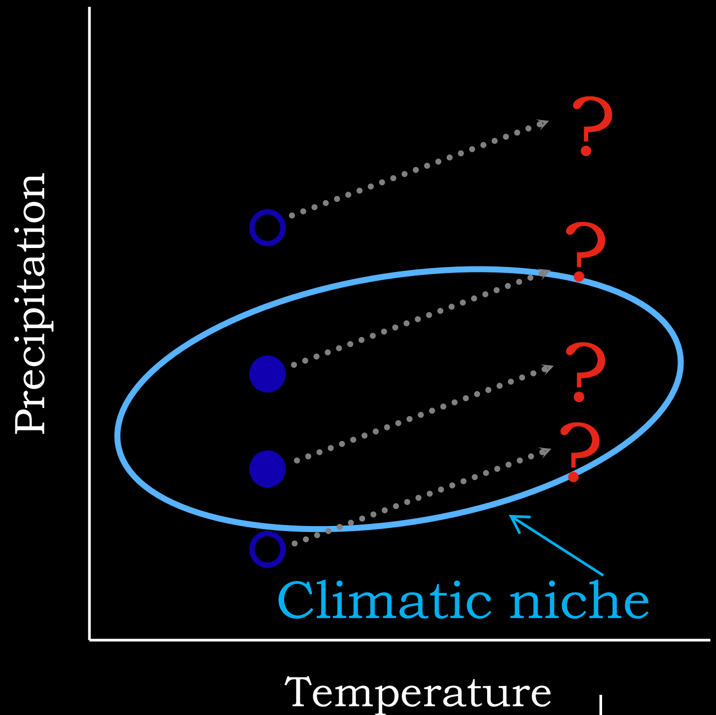
Tingley et al. 2009. PNAS 106:19637-19643.

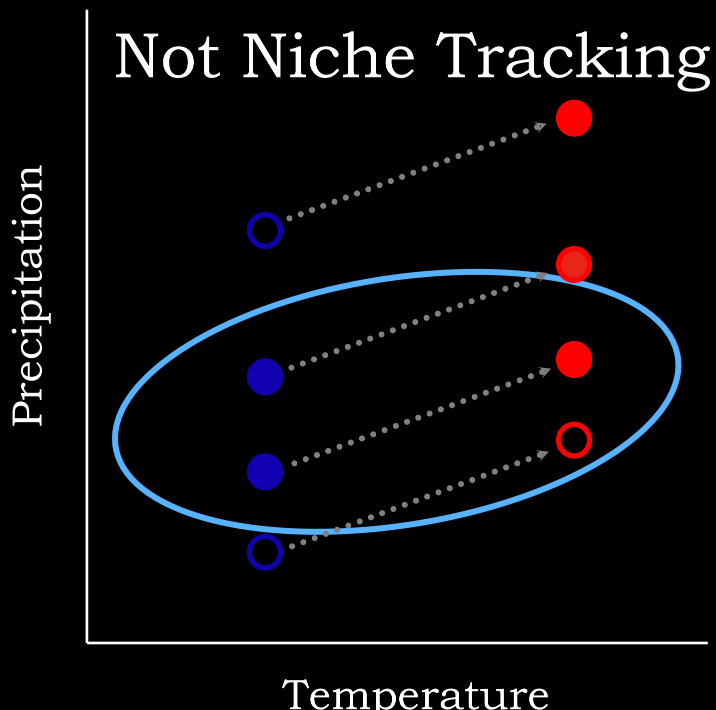
Grinnell Resurvey Project Transects Resurveyed and Climate Change Vectors

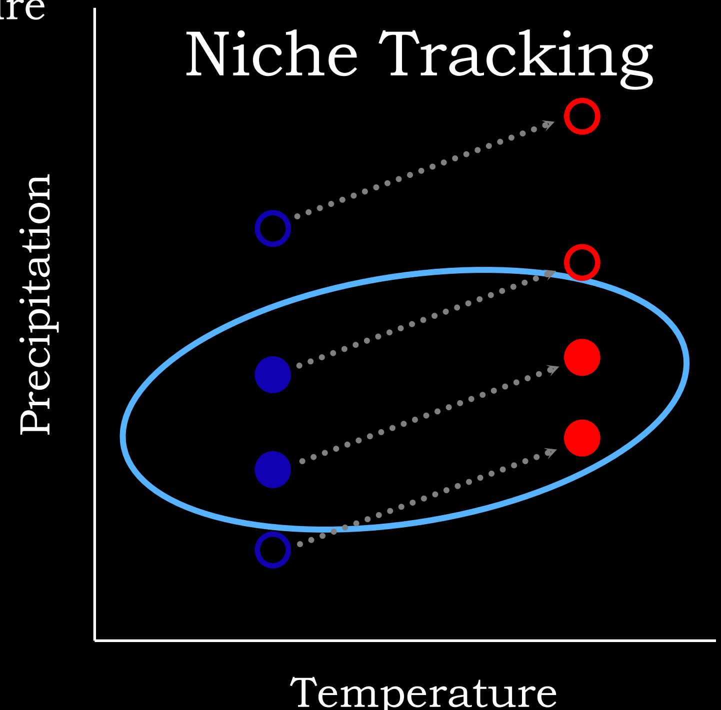




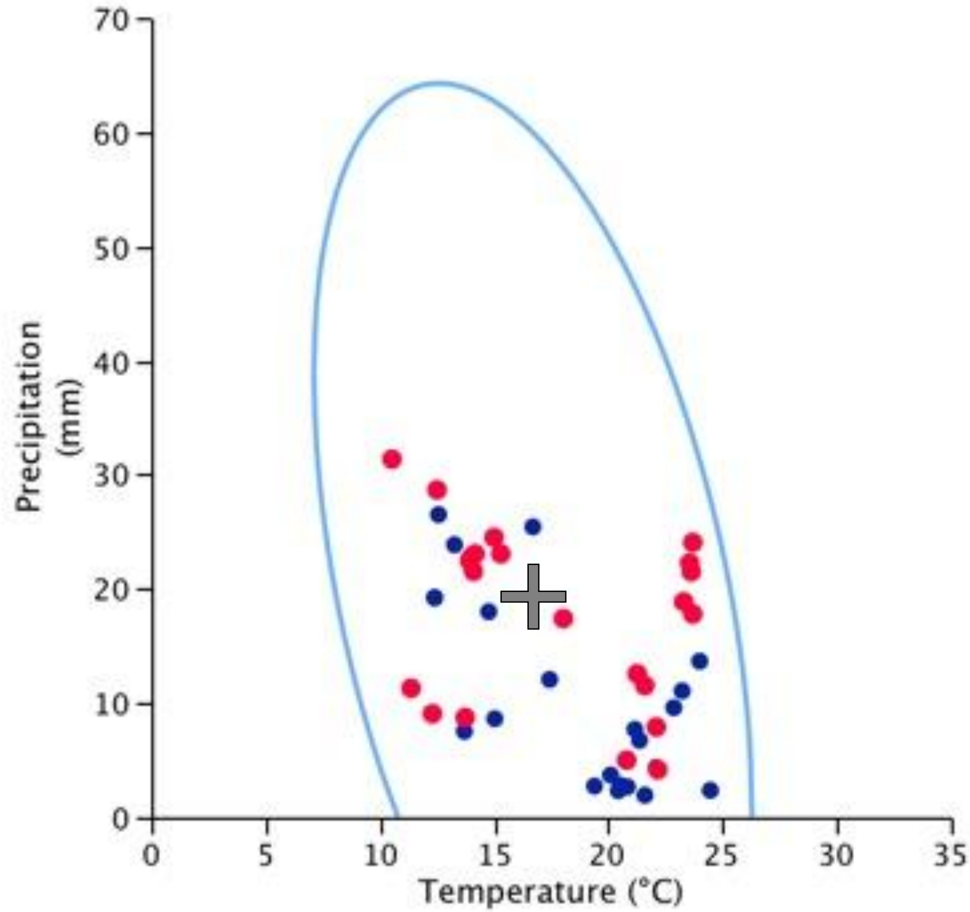
Niche Tracking: species follow limiting environmental boundaries through geographical space to remain in favorable climatic space





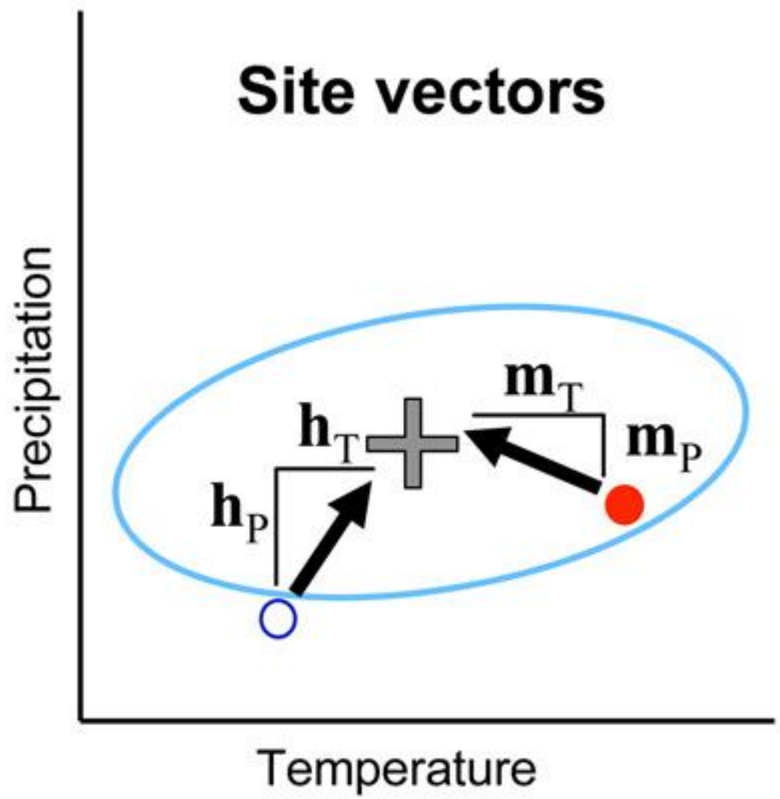


Measuring Niche Tracking



Specimens which were Historical (1860 -1940 with Lat/Longs breeding season only

Sites can be defined by vector components describing the position of a site (e.g., site 4) either historically (**h_T and h_P) or currently (m_T and m_P) relative to the climatic niche centroid. These site-specific vectors** are used in combinations as covariates of colonization and extinction in **Multi-Season Occupancy Models.**



91% of Species (N=53) Niche Tracked

Low elevation | Middle elevation | High elevation

Species	Tracking	Species	Tracking	Species	Tracking
Nuttall's Woodpecker	--	Violet-green Swallow	precip	Mountain Quail	temp
Oak Titmouse	precip	Lazuli Bunting	temp, precip	Dusky Flycatcher	temp
Bullock's Oriole	precip	Lesser Goldfinch	precip	Steller's Jay	temp
California Towhee	precip	Western Scrub-Jay	--	Red-breasted Sapsucker	temp
Acorn Woodpecker	precip	Canyon Wren	precip	White-headed Woodpecker	temp
Western Kingbird	precip	Spotted Towhee	precip	Green-tailed Towhee	temp
California Quail	precip	Black-headed Grosbeak	precip	White-crowned Sparrow	temp, precip
California Thrasher	--	Pacific-slope Flycatcher	temp	Mountain Chickadee	temp
Lark Sparrow	precip	Brewer's Blackbird	precip	Yellow-rumped Warbler	temp, precip
Bewick's Wren	precip	Cassin's Vireo	temp, precip	Townsend's Solitaire	temp
Ash-throated Flycatcher	temp, precip	Black-throated Gray Warbler	temp, precip	Pygmy Nuthatch	precip
Anna's Hummingbird	--	Northern Flicker	temp, precip	Hammond's Flycatcher	temp, precip
Bushtit	precip	Rock Wren	temp	Cassin's Finch	temp
Western Meadowlark	precip	Western Wood-Pewee	temp, precip	American Dipper	temp
Black Phoebe	--	Hermit Warbler	precip	Williamson's Sapsucker	temp, precip
Wrentit	precip	Western Tanager	temp, precip	Mountain Bluebird	temp, precip
Lawrence's Goldfinch	precip	MacGillivray's Warbler	temp, precip	Clark's Nutcracker	temp
Western Bluebird	temp, precip	Calliope Hummingbird	precip		

Species' elevation significantly associated with tracked gradient ($F_{3,49}$=20.4, P<0.001)

The 5 species that did not track their climate niche were urban colonists.

Species	Tracking	Species	Tracking	Species	Tracking
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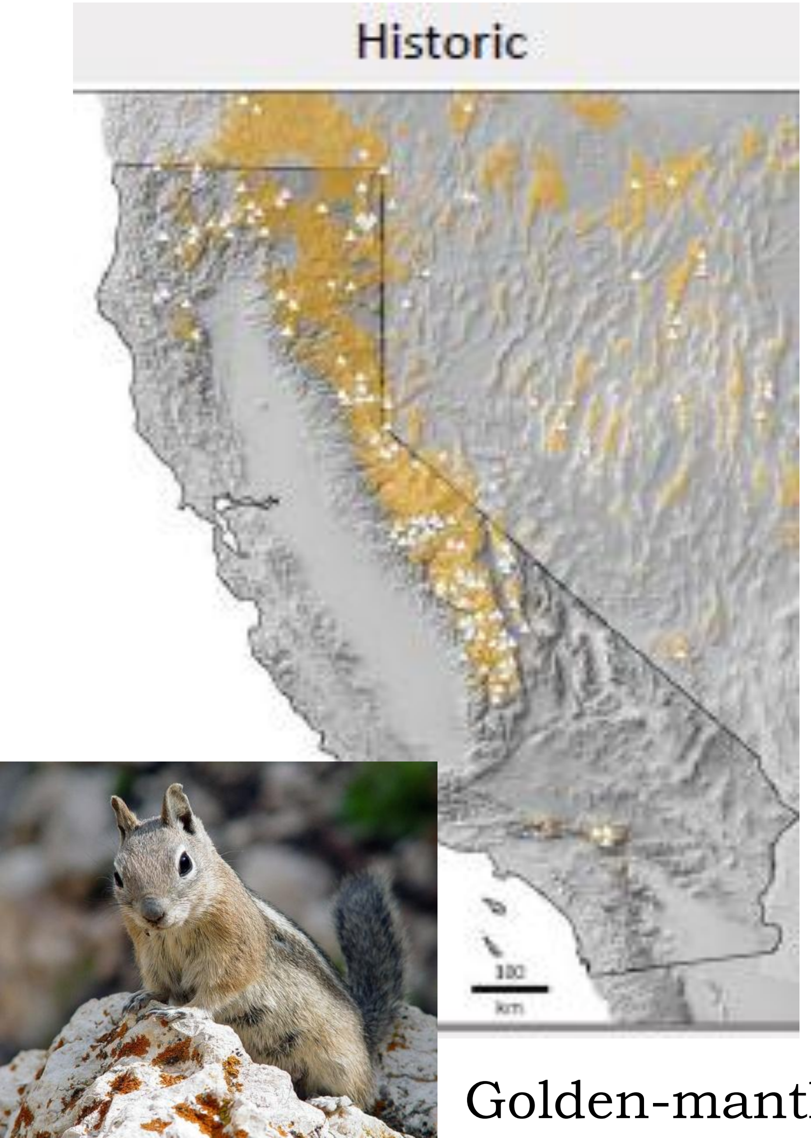
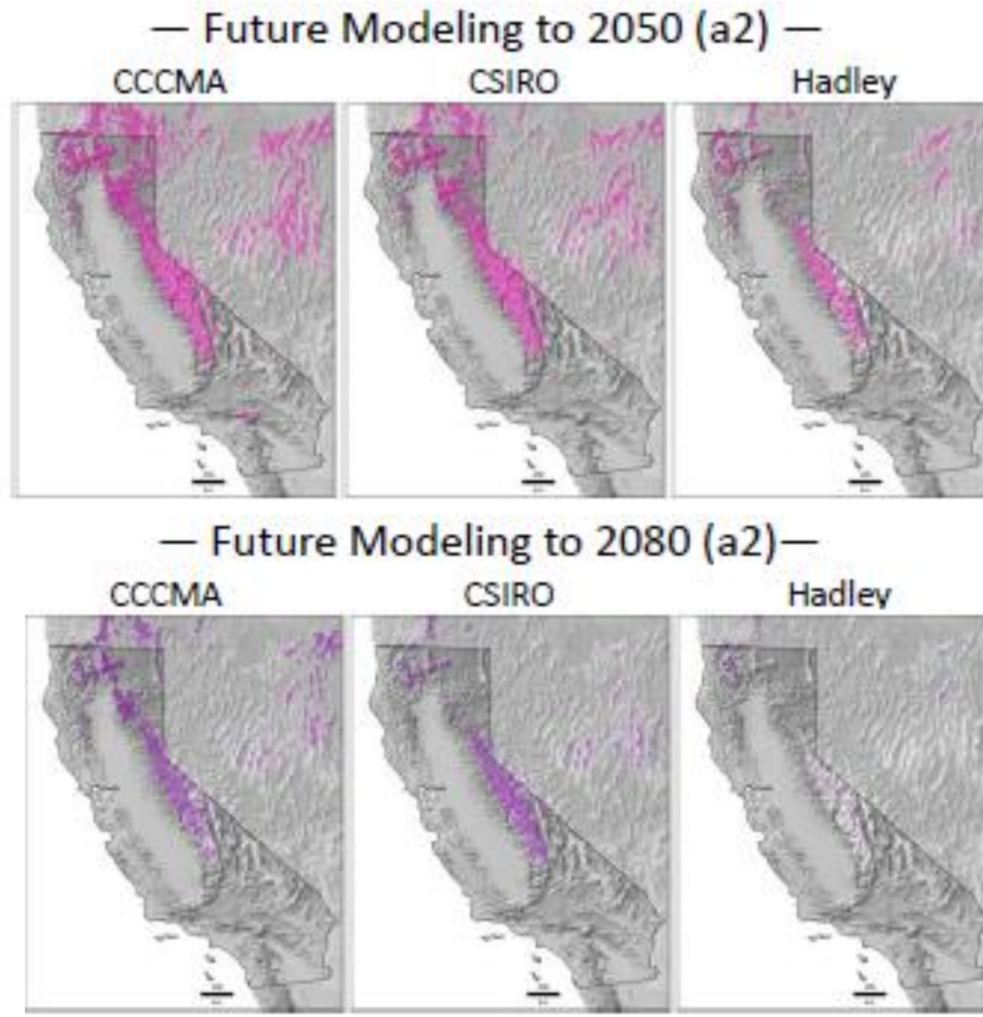
California Towhee	precip	Western Scrub-Jay	--	Red-breasted Sapsucker	temp
Acorn Woodpecker	precip	Canyon Wren	precip	White-headed Woodpecker	temp
Western Kingbird	precip	Spotted Towhee	precip	Green-tailed Towhee	temp
California Quail	precip	Black-headed Grosbeak	precip	White-crowned Sparrow	temp, precip
California Thrasher	--	Pacific-slope Flycatcher	temp	Mountain Chickadee	temp
Lark Sparrow	precip	Brewer's Blackbird	precip	Yellow-rumped Warbler	temp, precip
Bewick's Wren	precip	Cassin's Vireo	temp, precip	Townsend's Solitaire	temp
Ash-thr. Flycatcher	temp, precip	Black-thr. Gray Warbler	temp, precip	Pygmy Nuthatch	precip
Anna's Hummingbird	--	Northern Flicker	temp, precip	Hammond's Flycatcher	temp, precip
Bushtit	precip	Rock Wren	temp	Cassin's Finch	temp
Western Meadowlark	precip	Western Wood-Pewee	temp, precip	American Dipper	temp
Black Phoebe	--	Hermit Warbler	precip	Williamson's Sapsucker	temp, precip
Wrentit	precip	Western Tanager	temp, precip	Mountain Bluebird	temp, precip
Lawrence's Goldfinch	precip	MacGillivray's Warbler	temp, precip	Clark's Nutcracker	temp
Western Bluebird	temp, precip	Calliope Hummingbird	precip		

Species Distribution Models use climate to project occupancy (*Callospermophilus lateralis*)

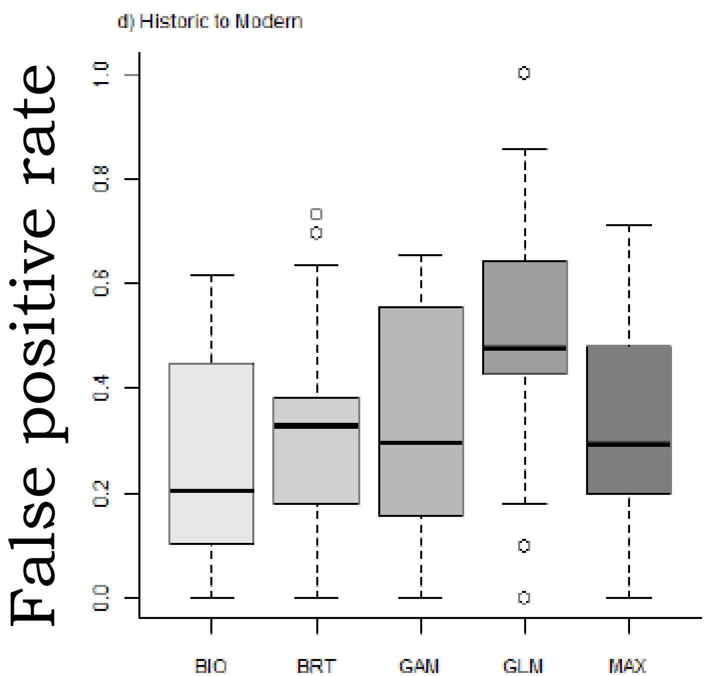




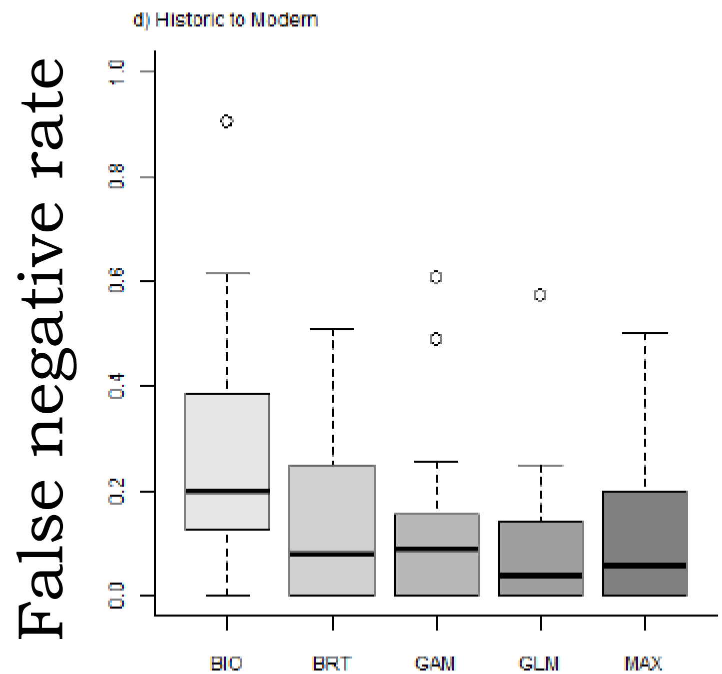
Golden-mantled ground squirrel

Species distribution models (SDMs) over-predict presence more often than absence.

Mean = 0.35



Mean = 0.14



SDMs that had good predictive performance for historic data did not perform well in projecting contemporary occupancy.

Conclusions

1. Someone has already walked where you walked – look for historic data to incorporate into your monitoring program.
2. Occupancy models have a central role to play in quantifying the impacts of climate change on range shifts and extinctions.
3. Elevation range changes in Sierra Nevadan small mammals and birds over the past 100 years mostly support patterns predicted by climate change, but species responses were idiosyncratic and much important spatial variation exists.
4. Birds appear to track changes in their bioclimatic niche and niche models had disappointing accuracy in projecting across the last 100 years, providing mixed support for their use to project future range shifts under climate change scenarios.

mvz.berkeley.edu/Grinnell/

cnr.berkeley.edu/~beis/BeissingerLab

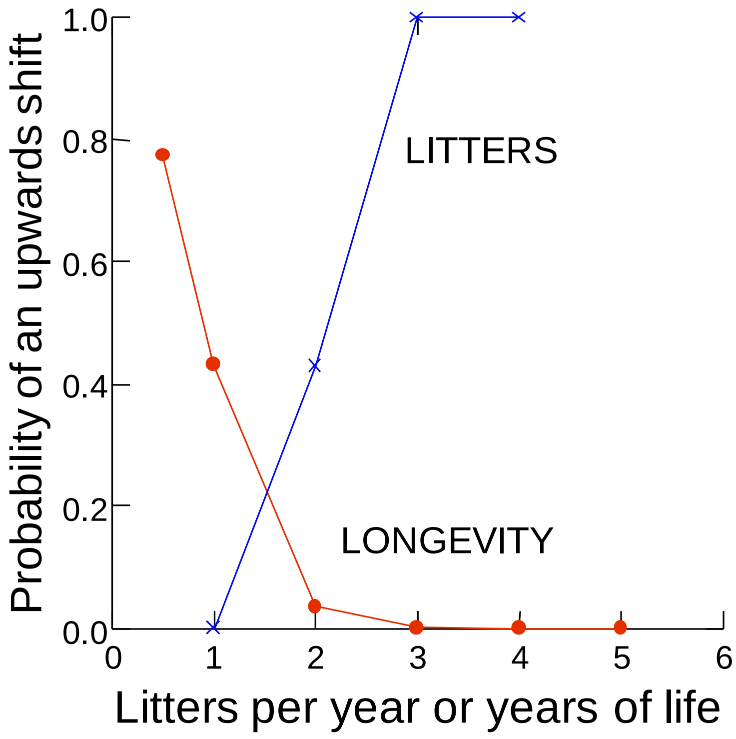
Thanks!

Which Mammal Species Moved?

1. Closely-related and ecologically-similar species responded idiosyncratically.

2. Lower Range Limit - Life Zone was the best predictor of a change.

3. Upper Range Limit - Life Zone, Longevity and Litter Size were the best predictors of a shift.



Multiple-Season Occupancy Models (MacKenzie et al. 2002, 2006)

$$\Psi_t = \Psi_{t-1}(1 - \varepsilon_{t-1}) + (1 - \Psi_{t-1})\gamma_{t-1}$$

Occupied **Undetected** **Not extinct**

Unoccupied **Colonized**

$$Pr(\boldsymbol{h}_2 = 000\,010)$$

$$= \varphi_1 \prod_1^3 (1 - p_{1,j})(1 - \varepsilon) + (1 - \varphi_1)\delta_1 \, x \, (1$$

$$- p_{2,1)} \, p_{2,2} \, (1 - p_{2,3})$$

Detected

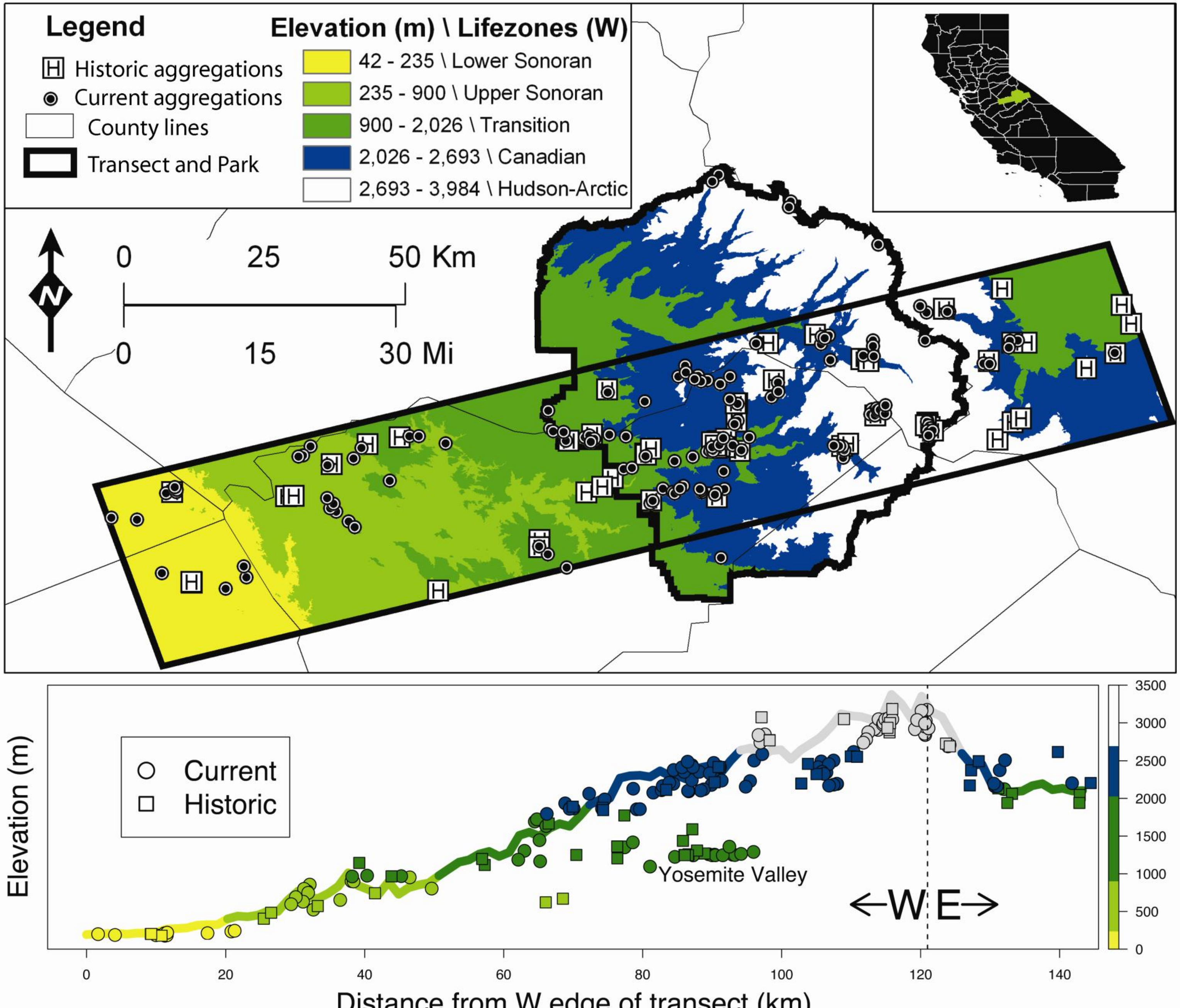
Our sites on public lands experienced little change.

Vogelsang Lake

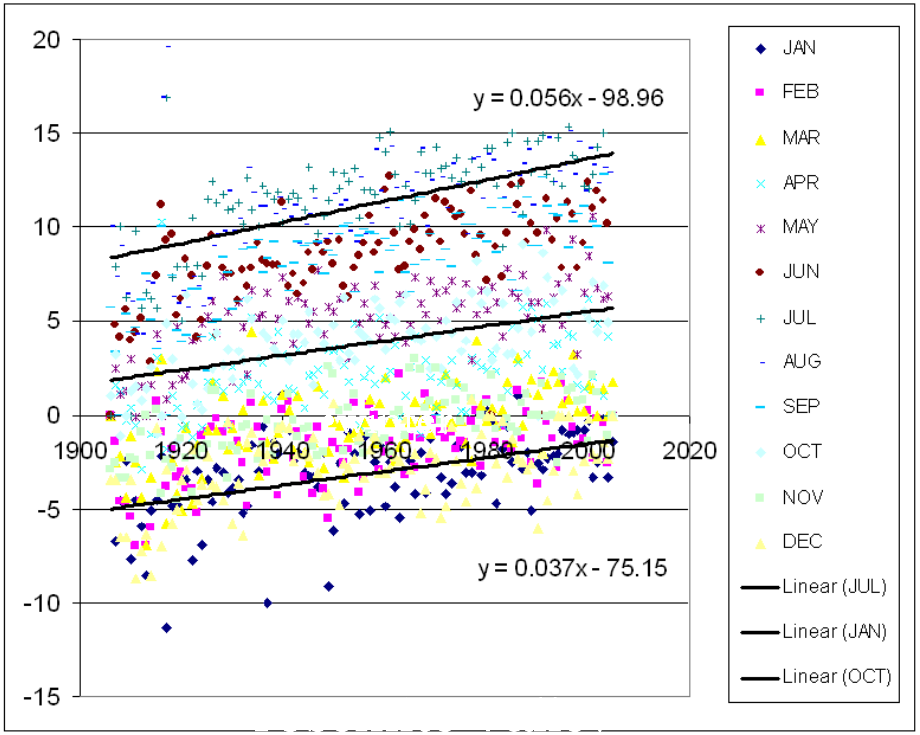
Note increased density and stature of white-bark pines

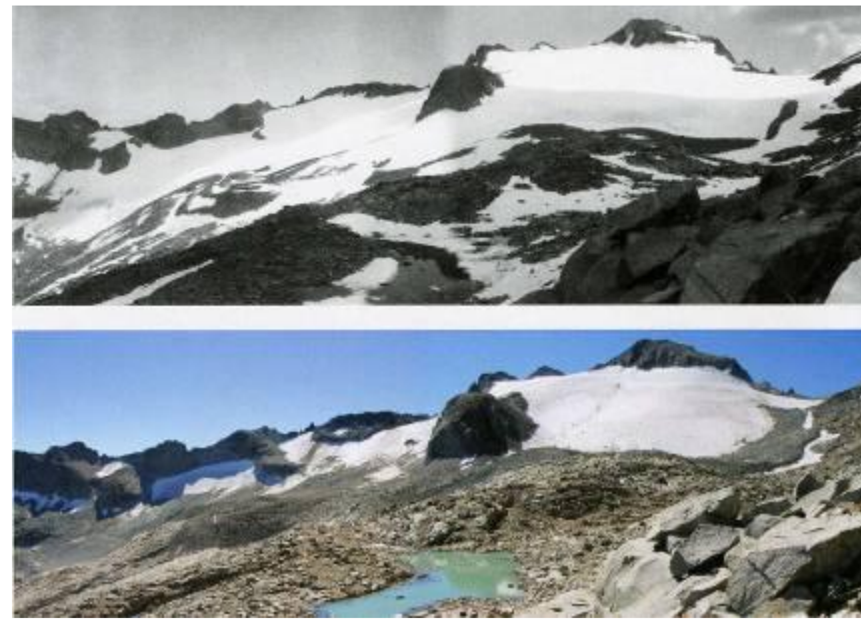
Extent of occurrence data		Data depiction Survey$_1$	Survey$_2$	Nondetection data	Temporal replication	Inference available	Biases to range estimation
Presence-only	*Site$_i$*	●	—	No	No	Extinction only	Pseudo-absence data leads to overprediction of historical range and of extinction, and no inference on colonization
	Site$_j$	●	—				
	Site$_k$	—	—				
Presence and non-detection		●	—	Yes	No	Extinction and colonization	False absences give under prediction of historical range and of extinction, and over prediction of colonization
		●	—				
		○	—				
Presence and estimable absence		●	●	Yes	Yes	Extinction and colonization	Probability of occupancy reduces false absence bias
		●	○				
		○	●				
Abundance		14	20	Yes	Yes	Extinction, colonization and change in population size	False absence bias reduced, but abundance comparisons bring new set of biases
		1	○				
		○	3				

Yosemite Transect



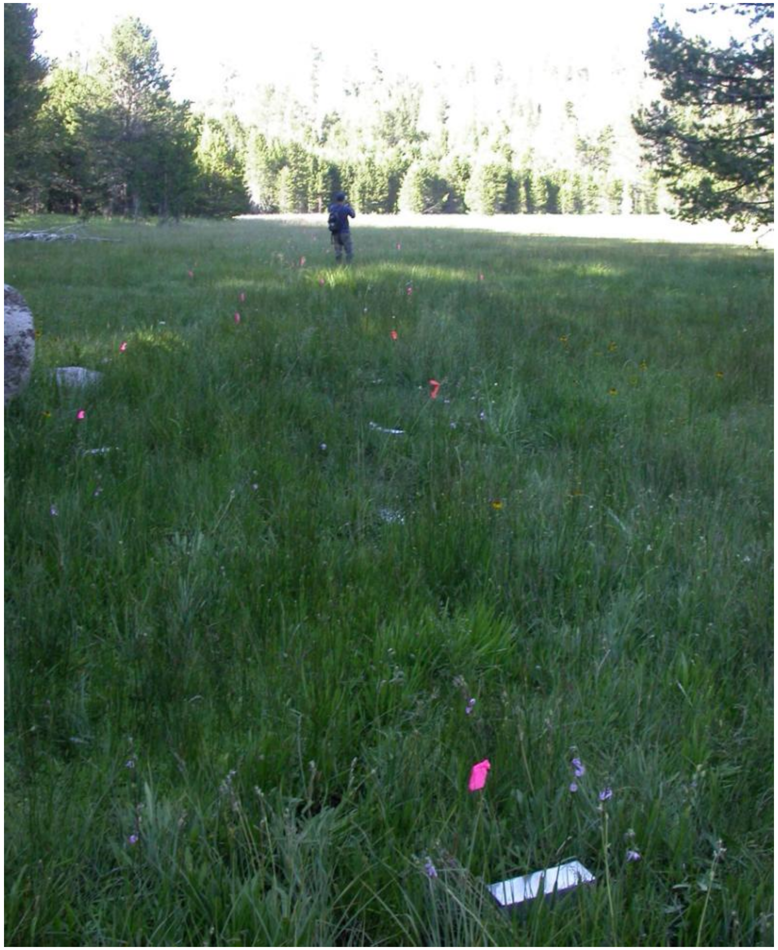
Signatures of Climate Change in Yosemite: Temperature Increase and Glacial Melt





The central Sierra has warmed by 3-4 C over the past 100 years!

Small Mammal Surveys (Jim Patton, Chris Conroy, & undergraduates)



Single Season Occupancy Models

For a series of species' presences (1) and absences (0) observed in repeated surveys at each site: h_1, h_2,...h_s (1,0,1,0,0,0)

$$L(\psi,\mathbf{p}\,|\,h_1,h_2,..h_s)=\left[\psi^{n.}\prod_{t=1}^{T}p_t^{n_t}(1-p_t)^{n.-n_t}\right]\times\left[\psi\prod_{t=1}^{T}(1-p_t)+(1-\psi)\right]^{N-n.}$$

where:

ψ - the probability a species is present (occupancy)

p - the probability of detection

N - the total number of sites surveyed

T - the number of distinct sampling occasions

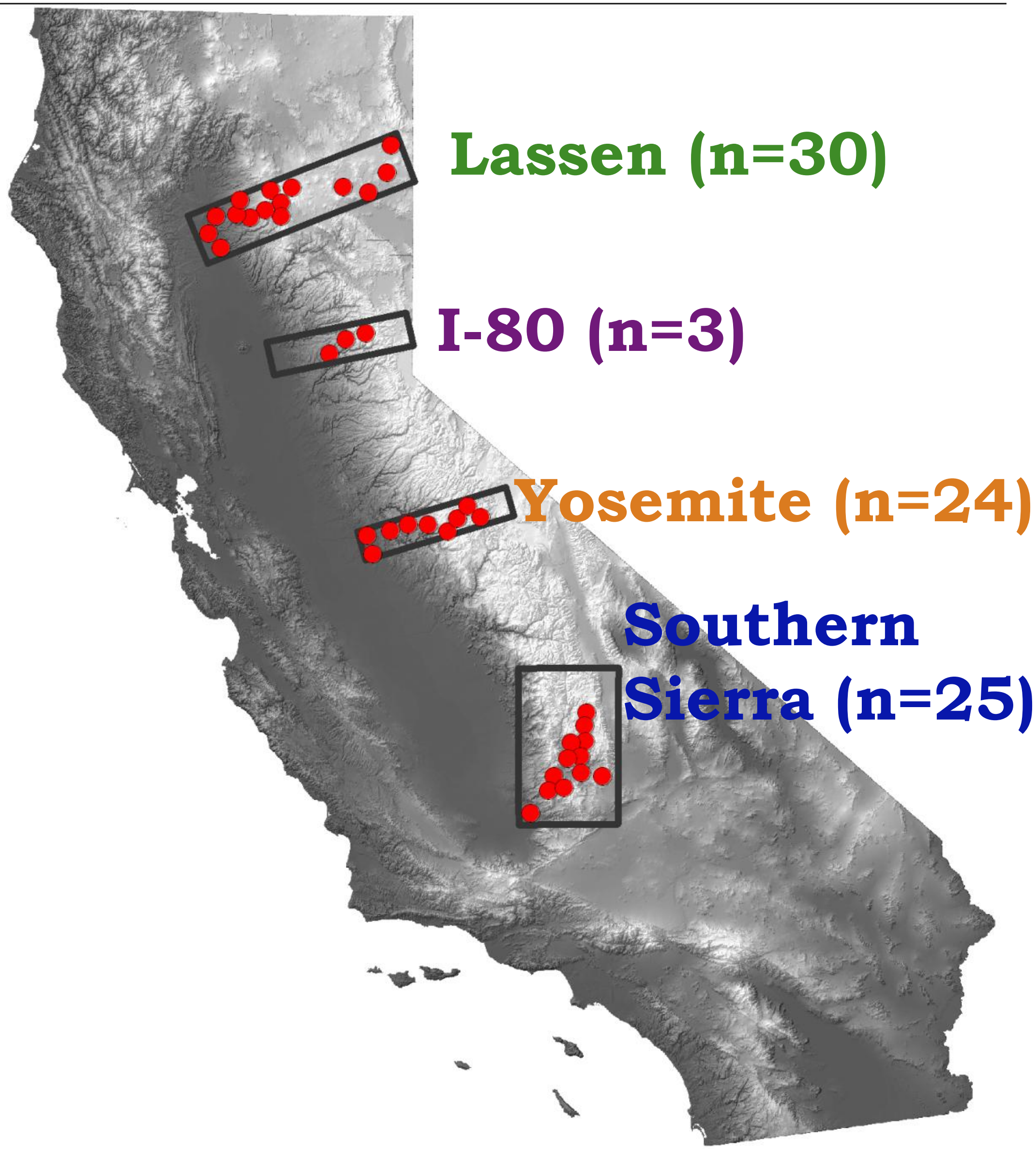
$n.$ - the total number of sites at which the species was detected at least once

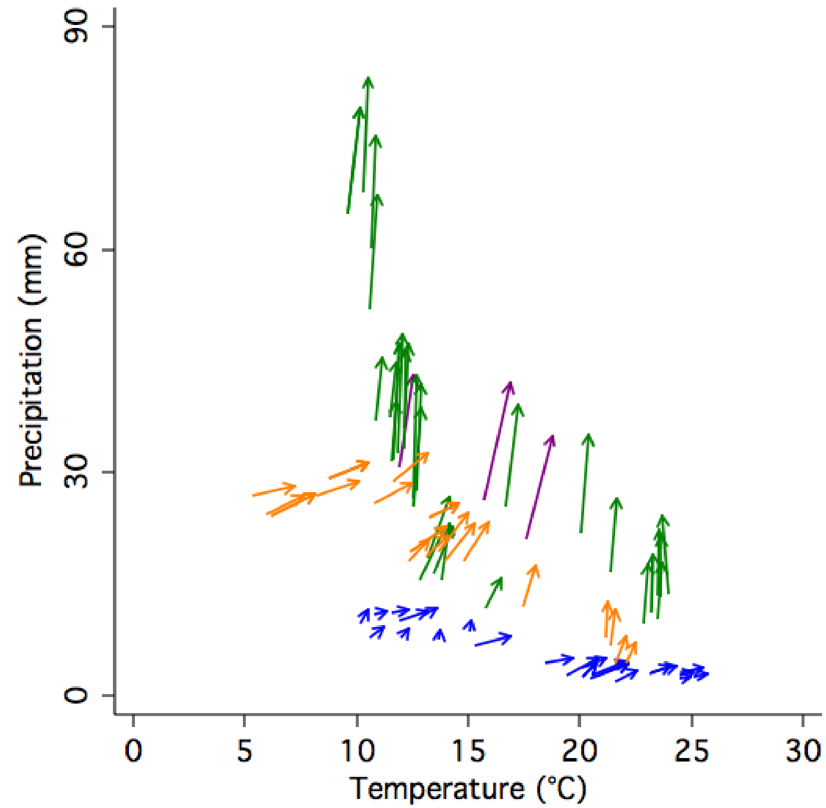
n_t - the number of sites where the species was detected at time t.

For each small mammal we fit 36 candidate detection models using:

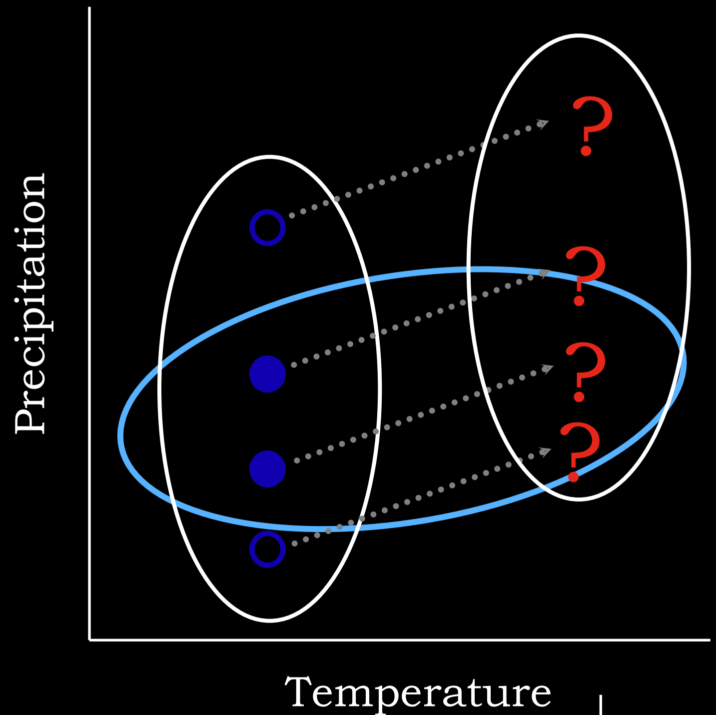
- **Era** (Grinnell vs. Modern)
- **Trend** (declining success by night)
- **Trapping effort** (mean and log number of traps per night)
- And **combinations** and **interactions** (multiplicative and additive) of the above four terms.

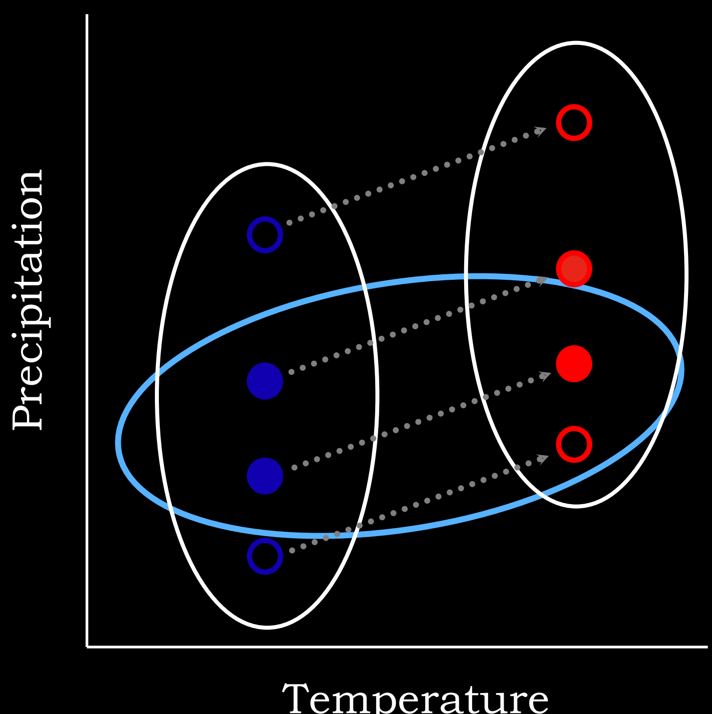
Then the 14 best detection models were each used with 8 potential occupancy models to evaluate hypothesized relationships of occupancy with era and elevation.

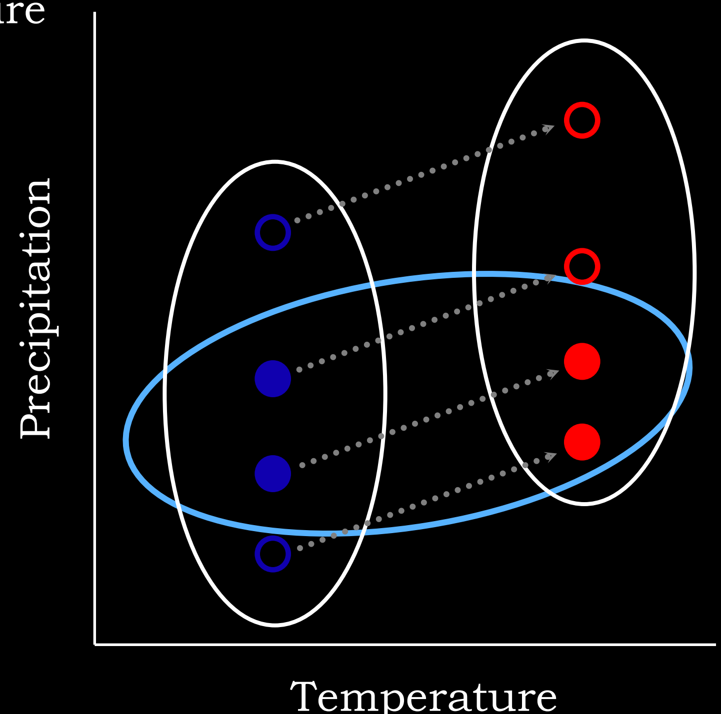

Lassen (n=30)
I-80 (n=3)
Yosemite (n=24)
Southern Sierra (n=25)

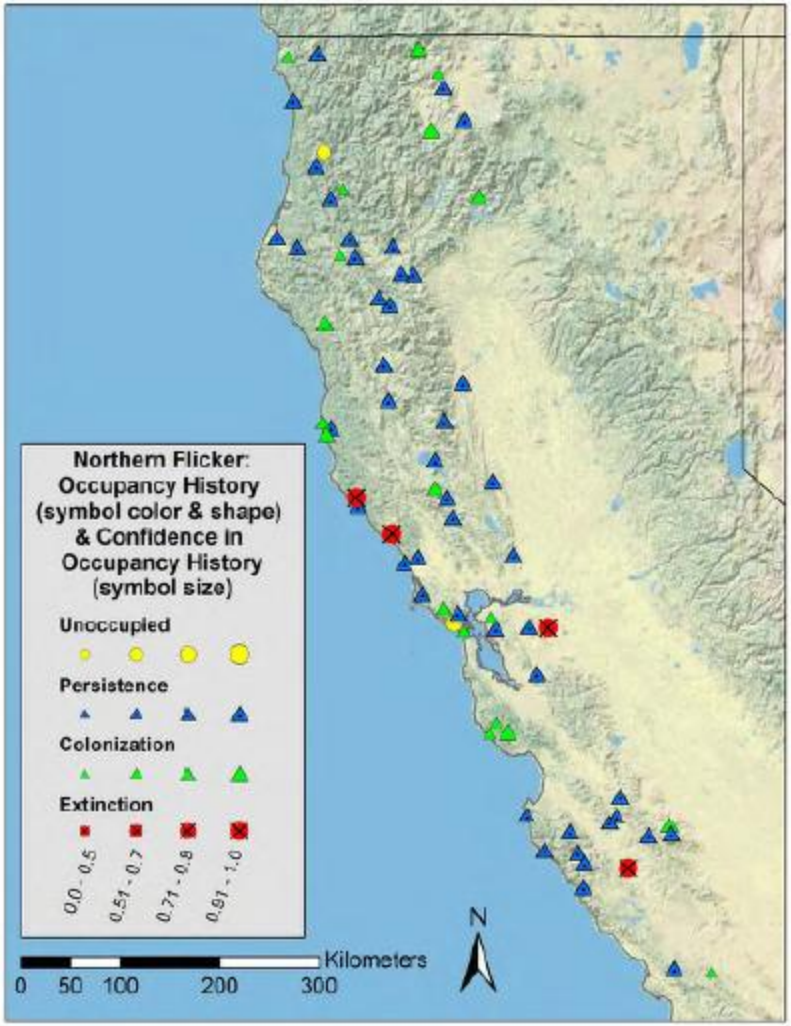

Precipitation (mm)
Temperature (°C)
0
30
60
90
0
5
10
15
20
25
30

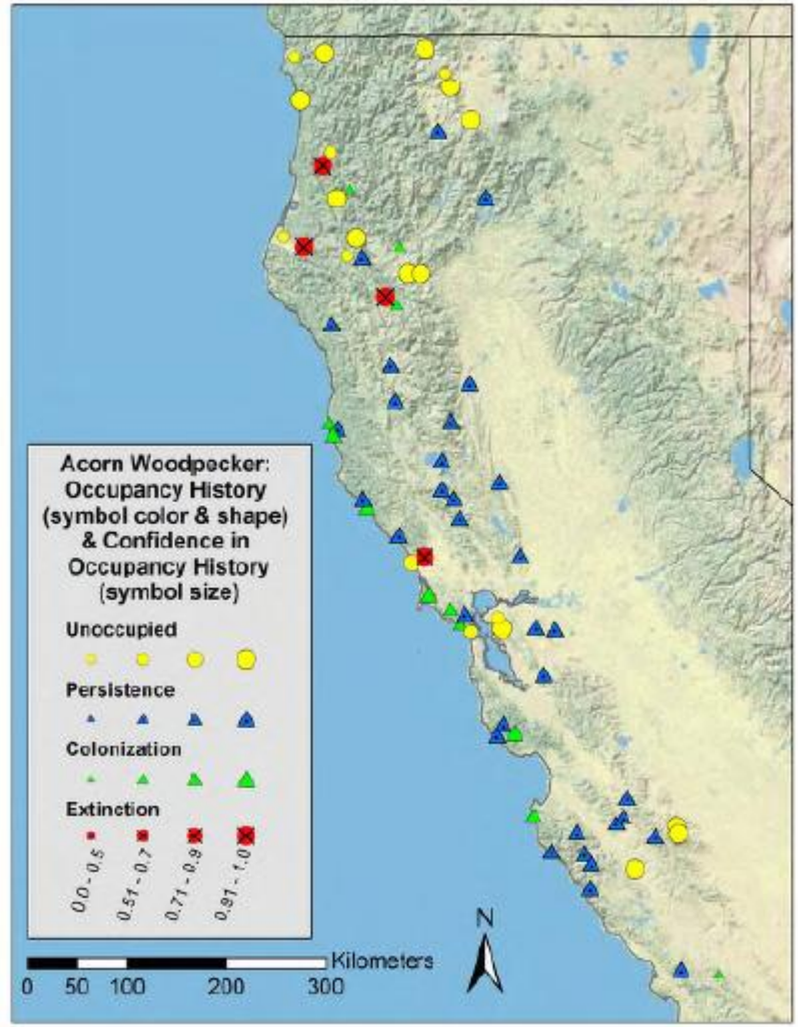
Niche Tracking: species follow limiting environmental boundaries through geographical space to remain in favorable climatic space



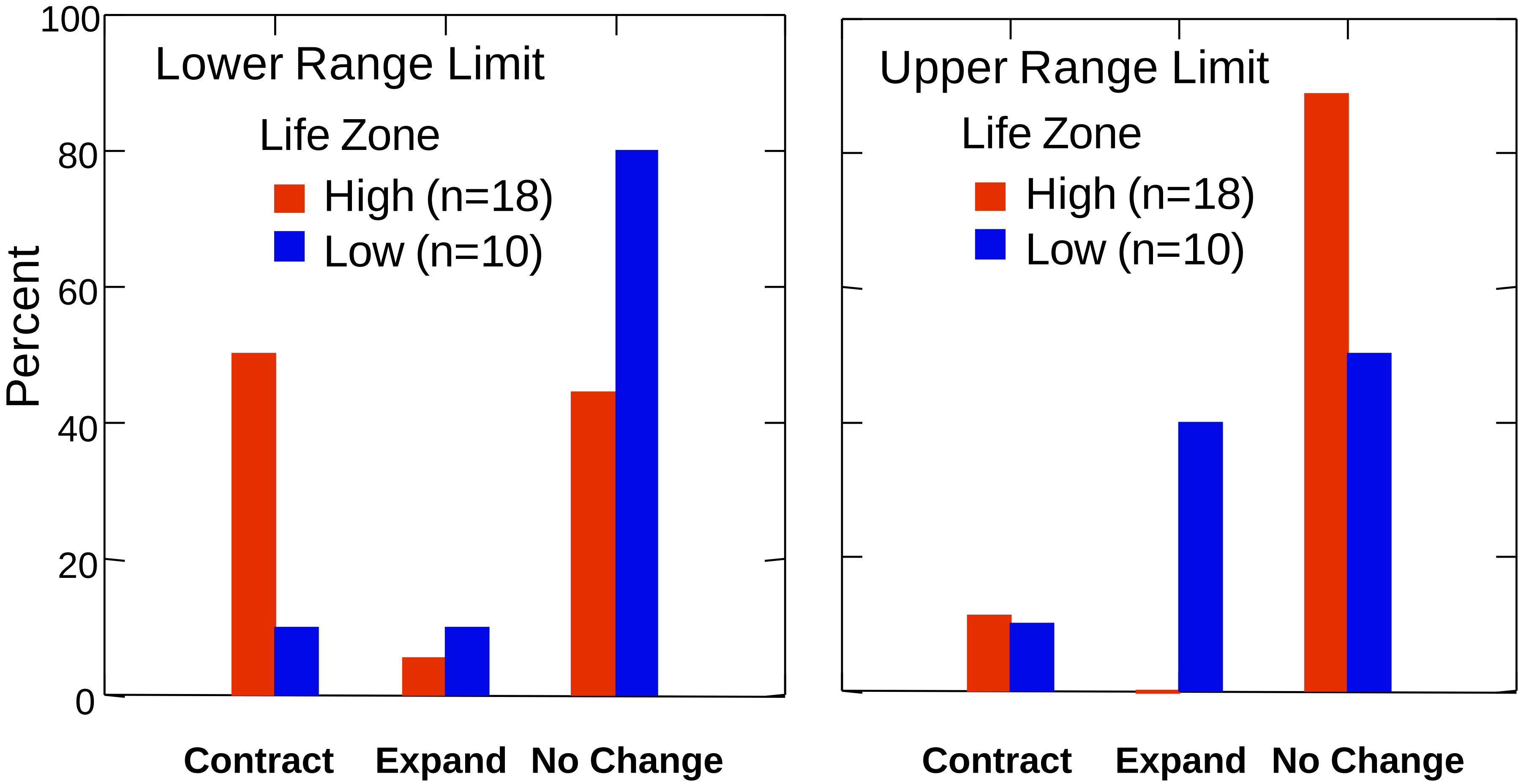





Northern Flicker:
Occupancy History
(symbol color & shape)
& Confidence in
Occupancy History
(symbol size)
Unoccupied
Persistence
Colonization
Extinction
0.0 - 0.5
0.51 - 0.7
0.71 - 0.8
0.91 - 1.0
Kilometers
0 50 100 200 300
N


Acorn Woodpecker:
Occupancy History
(symbol color & shape)
& Confidence in
Occupancy History
(symbol size)
Unoccupied
Persistence
Colonization
Extinction
0.0 - 0.5
0.51 - 0.7
0.71 - 0.9
0.91 - 1.0
Kilometers
0 50 100 200 300
N

High elevation species typically experienced range contractions, whereas low elevation species expanded their ranges upwards (X^2 = 8.8, *df* = 2, *P* = 0.012).



Moritz et al. 2008. Science 322: 261-264.

The Grinnellian Niche

"An explanation of this restricted distribution is probably found in the close adjustment of the bird in various physiological and psychological respects to a narrow range of environmental conditions…."

(Joseph Grinnell, *The Auk*, 1917)